DESIGN OF THE HGVPU UNDULATOR VACUUM CHAMBER FOR LCLS-II*

J. Lerch[†], J. Carter, P. Den Hartog, G. Wiemerslage
Argonne National Laboratory, Advanced Photon Source, Lemont, IL USA

Abstract

A vacuum chamber has been designed and prototyped for the new Horizontal Gap Vertically Polarization Undulator (HGVPU) as part of the LCLS-II upgrade project. Numerous functional requirements for the HGVPU assembly constrained the vacuum chamber design. These constraints included spatial restrictions to achieve small magnet gaps, narrow temperature and alignment specifications, and minimization of wall erosion and pressure drop within the cooling channels. This led to the design of a 3.5-meter length, thin walled, extruded aluminium chamber with interior water cooling. FEA stress analysis was performed to ensure the chamber will not fail under vacuum and water pressure. A cooling scheme was optimized to ensure water flow is sufficient to maintain temperature without the risk of erosion and to minimize pressure drop across the chamber.

INTRODUCTION

SLAC contracted the APS to design and manufacture a 3.5-meter undulator vacuum chamber (UVC) for use in an HGVPU as part of the LCLS-II upgrade project. The design process involved solving complex challenges that are becoming commonplace in next generation accelerator projects. The following is an overview of the UVC design process with an emphasis on the structural and thermal design challenges encountered.

STRUCTURAL DESIGN

Unlike most planar permanent magnet undulators, the HGVPU magnetic gap closes horizontally. This requires the UVC and its alignment fixture to be mounted directly to the HGVPU strongback in a vertical orientation (See Figure 1).

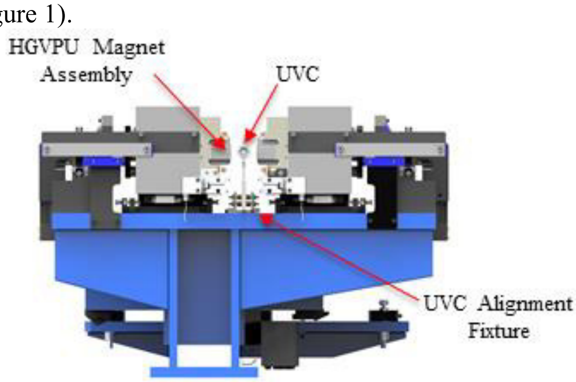

Figure 1: HGVPU and UVC final assembly.

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† Author Email: jlerch@aps.anl.gov

The chamber called for a straightness of $\pm 100\,\mu m$ along its length and to have a vertical position adjustment precision of $< 50\mu m$. This was accomplished by designing an extruded aluminium fixture that allowed the chamber straightness to be adjusted at 65 places along its 3.3-meter length. Tolerance control was used to maintain the vertical position precision. Figure 2 shows the final design of the alignment fixture.

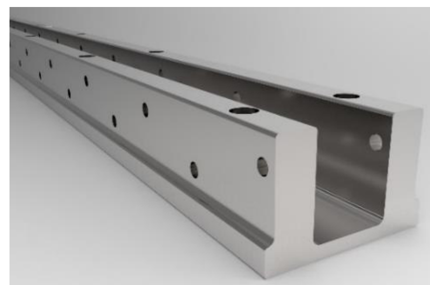

Figure 2: Alignment fixture end-isometric view.

The HGVPU closed gap is 7 mm during operation. SLAC defined the vacuum aperture geometry as a 5x11 mm racetrack. This called for the wall on either side of the aperture to have a thickness of 0.5 mm (See Figure 3).

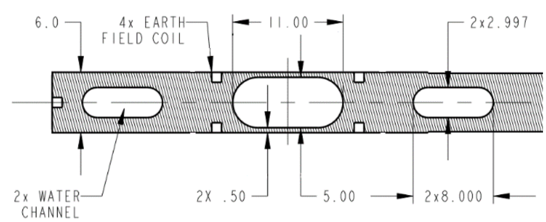

Figure 3: UVC nose cross section (dimensions are in millimetres).

To ensure that aperture wall deflection is minimized, 6063-T5 aluminium was used for the chamber material. This choice was based on previous design experience and verified using FEA (see Figure 4).

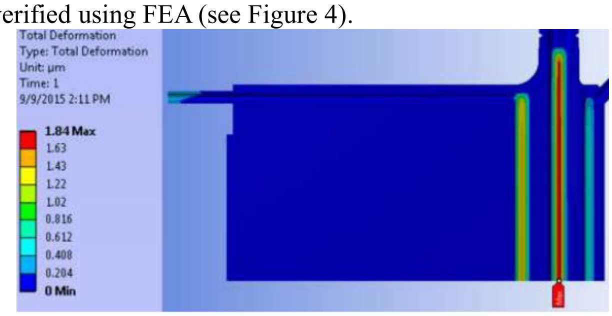

Figure 4: FEA deformation study. Max deformation found along aperture thin wall.

THERMAL DESIGN

Meeting SLAC's temperature stability requirement was one of the greatest design challenges to overcome. The UVC was required to not only mitigate a 3.3 $W/_m$ heat load but also maintain a total temperature change across the chamber length of ± 0.1°C. Further complicating the design were four earth field correction coils around the aperture that reduced the amount of conductive cross sectional area and required the water channels to be located further from the heat source (see Figure 3).

To reduce the heat load, an optimal flow range needed to be found. For aluminium, flow induced erosion rates become undesirable for long service components above 3 $m/_s$ [1]. Laminar flow rates were explored and found to be insufficient for meeting the temperature stability requirement with one or two cooling channels. A Reynold's number of 10,000 was used to establish a safety margin from the turbulent/transitional regime [2].

Prior to determining a final flow range, the number, size, and location of the water channel needed to be resolved. The hydraulic diameter of the optimal water channel size and Reynold's number were then used to find the final flow rate. During preliminary studies it was decided that two water channels were needed to meet the temperature stability requirement. The water channel height was set so all wetted surfaces remained at least 1/16 " away from an open surface based off the operational experience of the project engineer. This limited the height of the water channel to 3 mm. The position of the water channel with respect to the aperture was based off the location of a relief cut which helps technicians align the vacuum flanges during installation and alignment (see Figure 5).

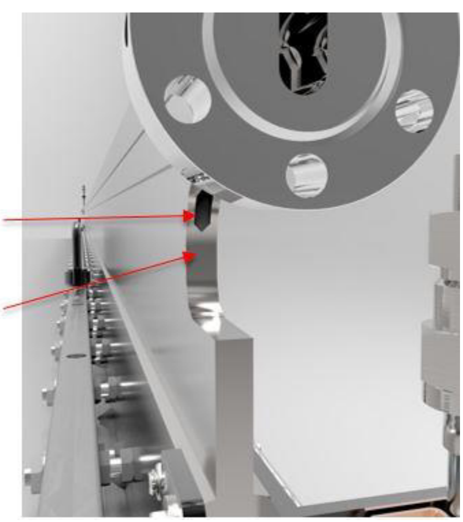

Figure 5: Vacuum flange relief cut.

The width of the water channel was determined using FEA. It was found that a channel width greater than 8 mm had a negligible effect on the temperature stability because the cooling surface area was too far removed from the heat source. It was also found that a channel width less than 8 mm reduced the cooling surface area (see Figure 6).

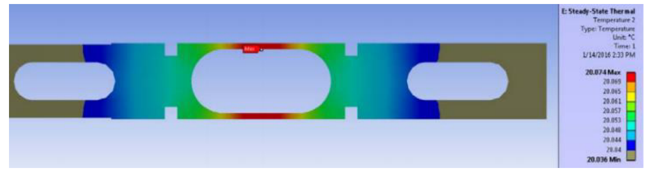

Figure 6: FEA thermal result for two 3x8 mm water channels.

For these reasons, two 3x8 mm cooling channels were located 4 mm from the earth field coil grooves. The final flow range based off the cooling channel size is 2.2 – 3 $m/_s$.

Due to the limited spatial constraints within the HGVPU, it was necessary to route the cooling flow through a machined circuit within the UVC. APS engineers worked closely with the chamber manufacturer to determine a method to route the water without inducing a large pressure drop. It was found that drilling the water circuits could lead to inaccurate routing and undesirable water channel geometry. To avoid increasing the number of internal turns in the water circuit (thereby increasing the pressure drop) it was determined that the ram EDM process would be utilized. This manufacturing process allowed for straight, repeatable cuts and the process also allowed the internal circuit geometry to match the chamber water channel geometry (see Figure 7).

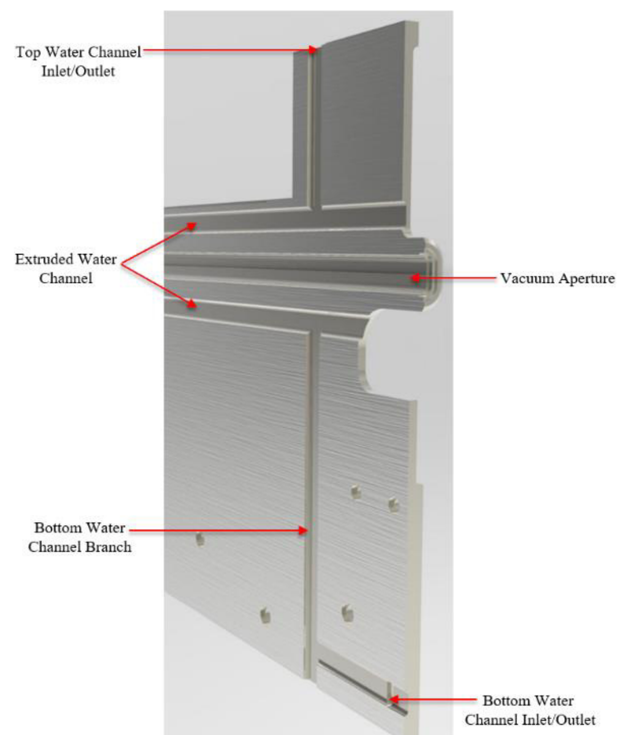

Figure 7: UVC cross section showing internal water circuit machining.

The inlet and outlet round tubing diameter was selected to closely match the cross sectional area of the cooling circuit, thereby further reducing the pressure drop and avoiding high flow rates.

Finally, determining the UVC water circuit connection to/from the main cooling system was investigated. It was found that both parallel routing and series routing provided enough cooling flow to meet the temperature stability requirement, however, the series routing required the assumption that the jumper needed across the chamber was adiabatic. Due to the large number of unknowns that exist in the undulator tunnel it was determined that this was a poor assumption. Therefore, parallel flow routing was recommended to SLAC (see Figure 8).

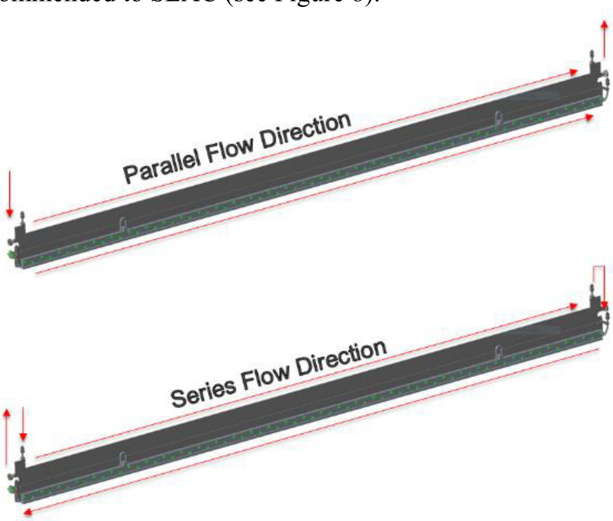

Figure 8: Parallel vs Series flow direction.

CONCLUSIONS

A 3.5-meter length, thin walled, extruded aluminium chamber with interior water cooling was developed for the LCLS-II upgrade projects (see Figure 9).

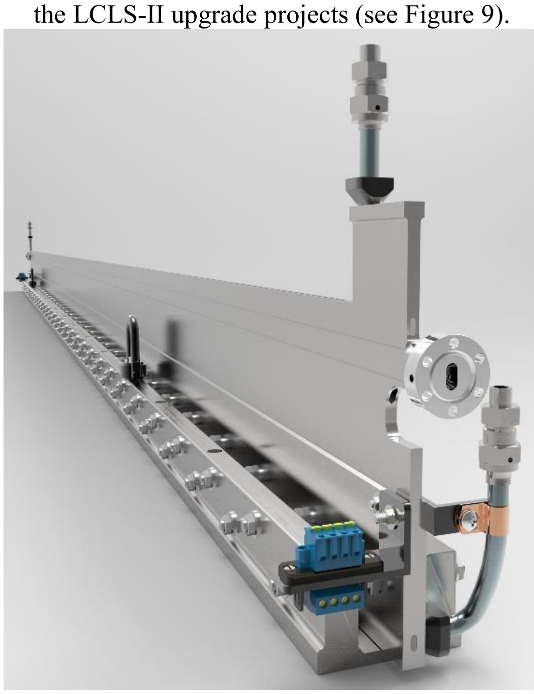

Figure 9: HGVPU UVC and alignment fixture.

Numerous challenges were encountered during the design of the UVC. The chamber aperture thin wall needed to deform minimally to allow clear beam passage. The chamber was also required to have a small temperature change across its 3.5-meter length. FEA stress analysis was performed to ensure the chamber will not fail under vacuum and water pressure. A cooling scheme was optimized to ensure water flow is sufficient to maintain temperature without the risk of erosion and to minimize pressure drop across the chamber.

ACKNOWLEDGMENT

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