ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB084

MECHANICAL DESIGN AND ANALYSIS OF THE PROPOSED APEX2 VHF CW ELECTRON GUN*

A. R. Lambert†, H. Feng, D. Filippetto, M. Johnson, D. Li, T. Luo, C. Mitchell, F. Sannibale, J. Staples, S. Virostek, R. Wells
Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Abstract

Normal conducting radio-frequency (RF) guns resonating in the very high frequency (VHF) range (30-300 MHz) and operating in continuous wave (CW) mode have successfully achieved the targeted brightness and reliability necessary for upgrading the performance of current lower repetition rate accelerator-based instruments such as X-ray free electron lasers (FELs), and ultra-fast electron diffraction (UED) and microscopy (UEM). The APEX2 (Advanced Photo-injector Experiment 2) electron gun is a proposed upgrade for the current LCLS-II injector, which was based on the original APEX design. In contrast, APEX2 is designed as a two-cell cavity operating at 162.5 MHz with a launching field at the cathode equal to 34 MV/m, producing a beam energy of 1.5 to 2 MeV, more than double APEX. Operation of the gun in this condition will require upwards of 200 kW of RF power, thus proper thermal management is crucial to achieve target performance. This paper describes the current design, thermal performance and tuning methods.

CAVITY DESIGN

The APEX2 [1] cavity design can be seen in Figure 1. The cavity is comprised of three main assemblies, the gun cell, the center wall and the 2nd cell.

The outer diameter of the cavity is 83.6 cm, the length from end to end is 31.1 cm. The gun cell and 2nd cell contain the majority of the cavity features, such as vacuum pumping, RF power input, sensing loop ports, and cooling channels. Both endwalls of the gun and 2nd cells have cooling channels buried within them. These channels are designed to be milled into the endwall, after which a copper cover or plug is electron-beam (E-beam) welded to form a leak tight seal; fluid inlet and outlet connection are fed into the channels using ports on the covers. A similar method is used on the cooling channels on the outer diameter of each cell. Additionally, there are cooling channels located in each of the nose cones, as these experience high heat flux during CW operation. Both a double helix spiral configuration and a shallow rectangular passage configuration have been studied, with the latter showing more promise due to geometrical constraints. It is intended that cavity endwalls are joined via E-beam weld to both the nose cones and outer walls, with the only brazes being those for the gun and 2nd cell nose cones.

E-beam welding is considered as the primary joining method as the annealed zone is small; the bulk of the copper retains its mechanical strength. For the endwalls this is particularly important as they are used for mechanical tuning of the cavity. It is intended that the

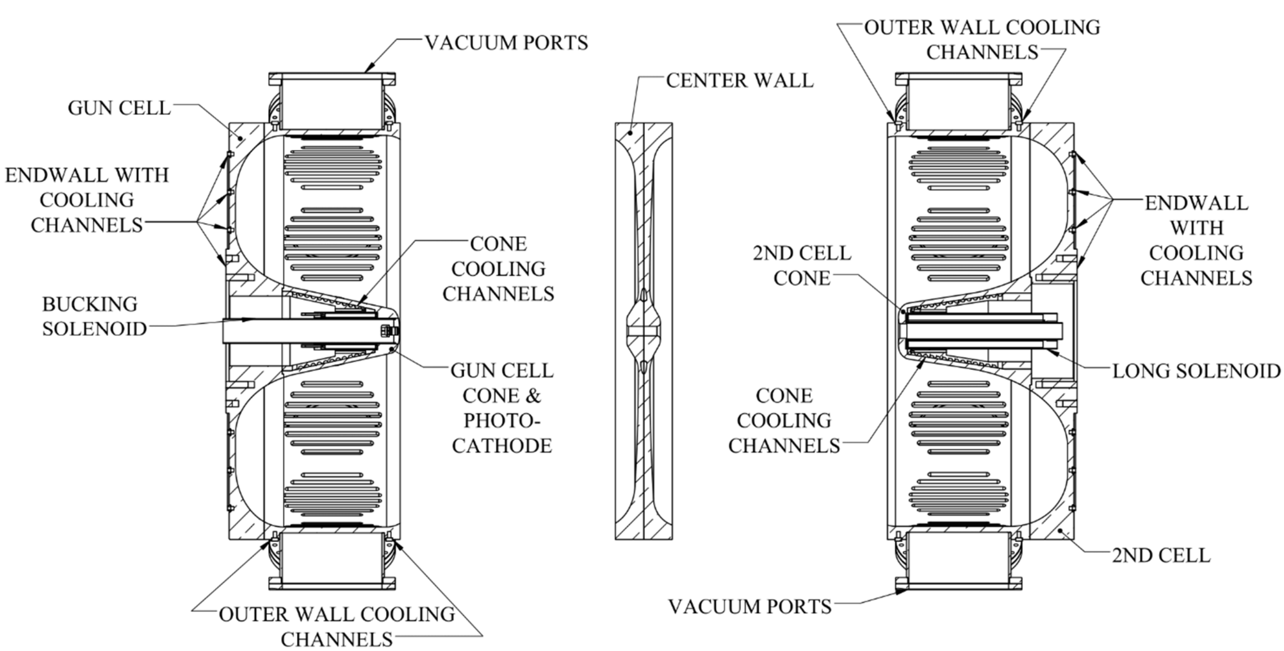

Figure 1: APEX2 cavity design.

* This work was supported by the Office of Science, U.S. Department of Energy under DOE contract number DE-AC02-05CH11231
† arlambert@lbl.gov

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB084

cavity be de-mountable, meaning that the gun cell, center wall, and 2nd cell are joined via a bolted connection, which allows for opening of the cavity. Vacuum sealing is accomplished using HELICOFLEX® all-metal seals, the target vacuum pressure is 10-10 – 10-9 torr. Center wall cooling passages are gun-drilled from the outer diameter, as seen in Figure 2.

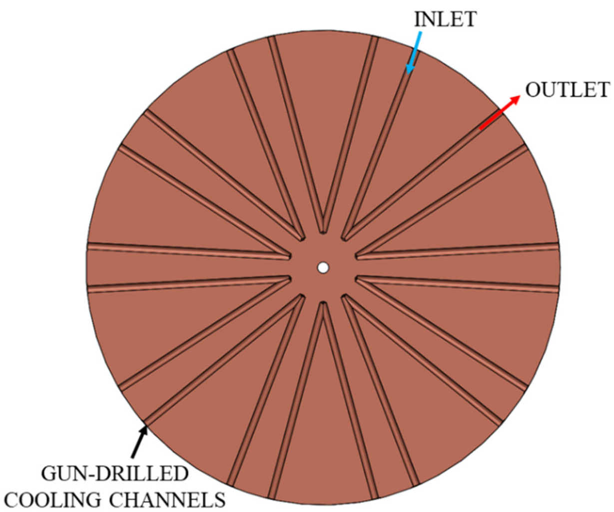

Figure 2: Gun-drilled cooling channels in the center wall.

Vacuum pumping on the cavity is accomplished via ten extended ports per cell, each with a 10” Conflat flange for direct pump mounting. The extended ports are copper and will be E-beam welded to the outer diameter of each cavity cell. Conflat flanges are constructed from explosion bonded copper-stainless steel; a copper-copper E-beam weld joins flange to tube. Pumping slots machined into the cavity outer diameter are sized to maximize conductance whilst minimizing power leakage. The pumping port geometry is shown in Figure 3.

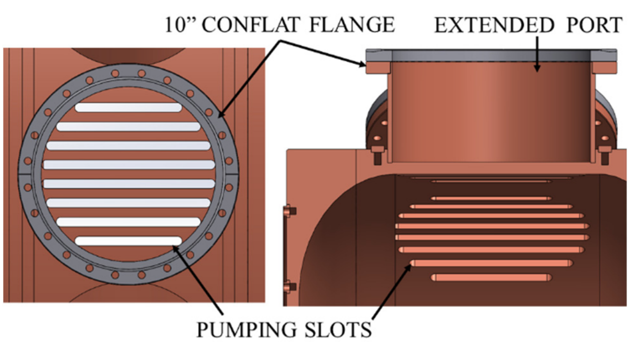

Figure 3: Vacuum port design.

Pumping at ultra-high vacuum (UHV) is achieved using St 172 (Zr-V-Fe) getter material with a hydrogen pumping speed of 400 l/s, combination getter/ion pumps are used for noble gases. Cleanliness of the inner surface of the cavity is instrumental to achieving UHV, previous experience and success with CO_2 snow-cleaning will be leveraged for APEX2.

Power is delivered to the cavity via two RF coupling ports per cell, located at 180 degrees with respect to each other. Each cell also possesses two sensing loops, similar to APEX.

RF-THERMAL ANALYSIS

Evaluation of the previously discussed cooling features is crucial for guiding the cavity design. To simulate the thermal performance of the cavity, an axi-symmetric 18-degree wedge model was created and meshed using ANSYS Multiphysics. Finite Element Analysis (FEA) performs RF analysis on the vacuum volumes for both cells. The solution of this analysis is used to calculate input heat flux in a thermal analysis with assumed CW operation. The heat flux is plotted in Figure 4.

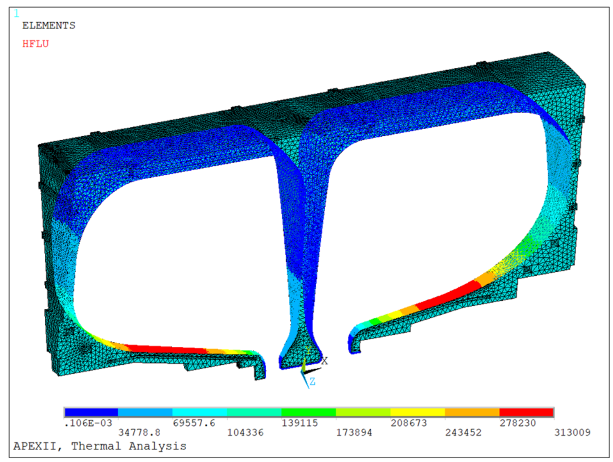

Figure 4: Cavity wall heat flux (W/m^2).

Cooling channels in the cavity have a surface convection boundary condition applied to simulate the high-Reynolds flow, the bulk temperature of the fluid is assumed to be 22.0°C. Cavity temperatures are plotted in Figure 5.

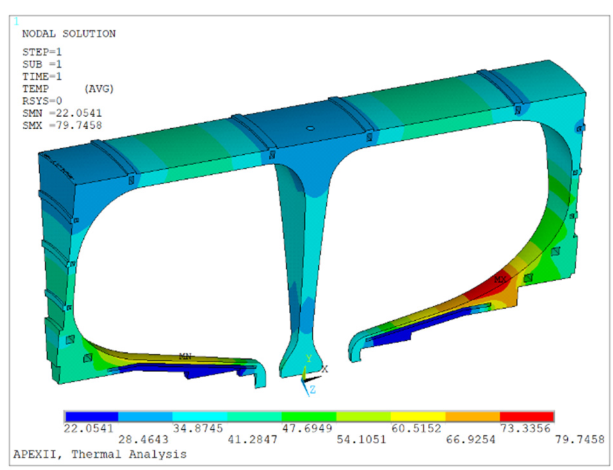

Figure 5: Steady-state CW temperature contours (°C).

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPRB084

The maximum temperature of 79.7°C is found in the 2nd cell, and the maximum temperature in the gun cell is 66.9°C. Importantly, the temperature in the cathode region is less than 40°C, as no reduction in K-Cs-Sb photocathode lifetime have been observed at operating temperatures up to 55°C [2]. Overall wall temperatures range from 28 to 54°C. The gun-drilled cooling passage in the center wall effectively keeps its temperature below 47°C. The calculated cell frequencies, maximum heat fluxes and power from the FEA simulations are summarized in Table 1 below Total heat load in the two-cell cavity is 173.5 kW..

Table 1: Summary of RF-Thermal Results

Parameter	Gun Cell	2nd Cell
Frequency [MHz]	160.6	163.3
Max. Heat Flux [W/cm^2]	30.1	31.3
Heat Load [kW]	85.4	88.1

CAVITY TUNING ANALYSIS

Deforming the cavity endwalls is a demonstrated method of tuning on both the APEX and LCLS-II guns, and is likewise adopted for the APEX2 cavity. Several different endwall thicknesses versus varying applied loadings were simulated using ANSYS Mechanical, the results of which are plotted in Figure 6.

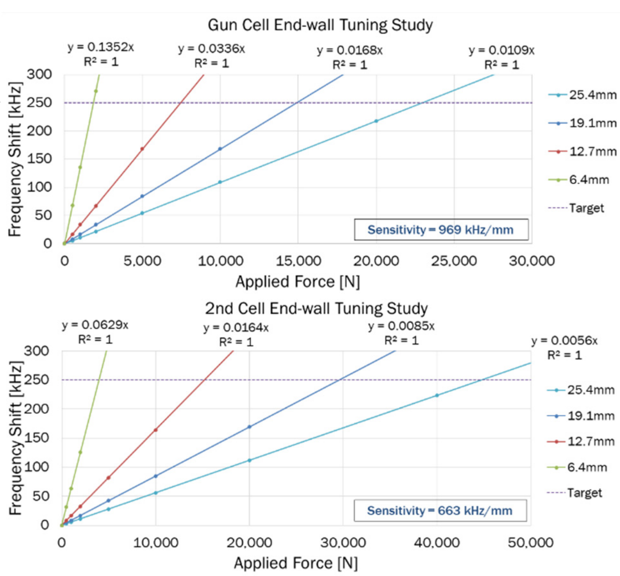

Figure 6: Endwall tuning study, frequency shift vs applied force, note that force in figure is 1/4th of required value due to symmetry boundary conditions in analysis.

As Figure 6 shows, the gun cell is more sensitive to the endwall deflection with a sensitivity of 969 kHz/mm, while the 2nd cell has a sensitivity ~2/3rd of that at 663 kHz/mm. The target tuning bandwidth is +/- 250 kHz. Endwall stresses due to tuning are below yield, with maximum von Mises stress for both the gun and 2nd cells at 30.5 MPa and 49.4 MPa respectively, as seen in Figure 7.

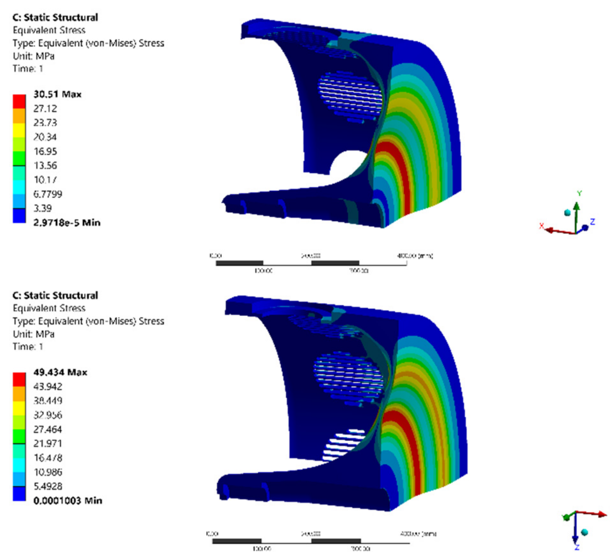

Figure 7: Stress (MPa) due to maximum required tuning load, gun cell (top) and 2nd cell (bottom).

Elastic deformation of the endwall will be accomplished using bi-directional (compression and tension) tuners. Force is generated using a combination motor driven screw actuator for coarse adjustment, while a lead zirconate titanate piezoelectric (PZT) ceramic actuator is used for fine adjustment [3].

CONCLUSION

The APEX2 engineering design is progressing well in the areas of cavity structure, thermal management, tuning and vacuum systems. Future work includes weld joint design, support structure, and cooling channel plumbing.

ACKNOWLEDGMENT

The author would like to acknowledge the efforts of the LBNL physics and engineering design teams.

REFERENCES

[1] F. Sannibale *et al.*, "Upgrade possibilities for continuous wave RF electron guns based on room-temperature VHF technology", *Phys. Rev Accel. Beams,* vol. 20 p. 113402, 2017. doi:10.1103/PhysRevAccelBeams.20.113402

[2] Z. Ding *et al.*, "Temperature dependent quantum efficiency degradation of K-Cs-Sb bialkali antimonide photocathodes grown by a triple-element codeposition method", vol. 20 p. 113401, 2017. doi:10.1103/PhysRevAccelBeams.20.113401

[3] R. P. Wells *et al.*, "Mechanical design and fabrication of the VHF-Gun, the Berkeley normal-conducting continuous-wave high-brightness electron source", *Review of Scientific Instruments,* vol. 87, no. 2, p. 023302, Feb. 2016. doi:10.1063/1.49418