A CONTINUOUS WAVE, NORMAL CONDUCTING, L-BAND PWT PHOTOELECTRON GUN*

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Abstract

A normal-conducting, L-band, photoelectron gun in an ultra high vacuum (UHV) accelerating structure called the Plane Wave Transformer (PWT) (DULY patent no. 6,744,226) integrated with an activated, strained-lattice GaAs photocathode, as a continuous wave (CW), polarized electron source is being developed by DULY Research Inc. The RF gun will simplify the CEBAF photoinjector design by replacing the direct current (DC) gun, buncher cavities and a 200-500 keV capture section. The compact PWT design provides a "stiffer" beam that is less subject to space charge blowup. In addition, a higher field gradient at the photocathode would provide the means to overcome the space and surface charge limitations [1] that are particularly problematic for a high current density beam.

INTRODUCTION

A standing-wave, 1-cell, CW, L-band, π-mode PWT photoinjector (Figure 1) with an open cavity is formed between an iris-loaded disk that is supported and cooled by water pipes anchored to the endplates. A GaAs photocathode is placed at the opening in the center of the back endplate. The structure has an open annular space between the disk outer edge and the cavity wall. In our polarized electron PWT gun design, the outer cavity wall is a sieve that has longitudinal slots providing UHV pumping paths. The width of the slots is chosen so that the RF wave is evanescent inside. A coaxial TEM-like standing wave in the annular region is coupled to a TM01-like mode on the axis of the cavity. The RF input coupler uses a coax design similar to the TESLA gun [2]. This design allows the PWT cavity to be connected to a UHV pumping chamber housing non-evaporative getters (NEG). Two emittance compensating solenoids are located close to the cathode.

For high-gradient (6 MV/m) CW operation, the RF gun will be powered by a CW klystron with high power (~60kW) so that photoelectrons can be captured and accelerated efficiently in the RF cavity. Simulations showed that adequate cooling of the normal conducting PWT gun can be achieved under the high power CW operation. RF heating of the PWT cavity will be dissipated by convection using six water-carrying pipes that connect to internal channels embedded in the disk and endplates. An orifice in two of the inlet pipes controls the ratio of the flow into the disk channel and the flow that continues into the endplate. A separate cooling circuit runs through the front endplate of the cavity. Still another circuit feeds water through longitudinal channels inside the vacuum-RF sieve. The three separate circuits allow a high degree of flexibility to effectively cool the cavity uniformly (see Figure 2).

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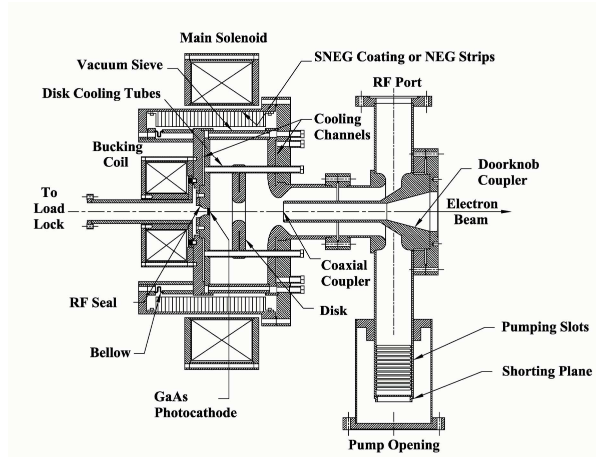

Figure 1: Schematics of a one-cell, CW L-Band PWT polarized electron gun.

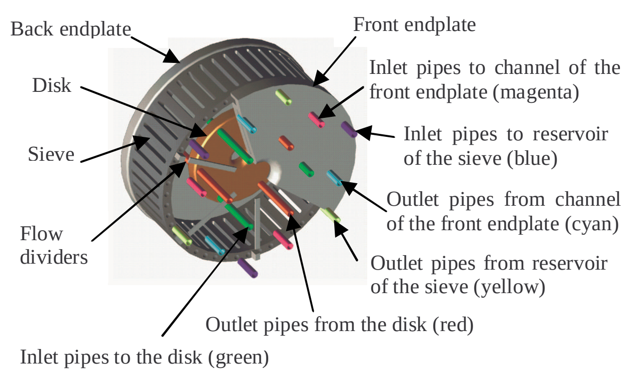

Figure 2: Cooling circuits for the 1-cell PWT.

ULTRA-HIGH VACUUM DESIGN

The unique design of the PWT gun attains ultra high vacuum by means of the high vacuum conductance of the open structure and efficient UHV pumping with NEG via a sieve that separates the RF cavity and an external pressure vessel. The choice of materials of construction is also important for achieving an ultra high vacuum. The outgassing rate of stainless steel, especially after high temperature bakeout, is significantly lower than that of copper. Aluminum 6061 [3] also has a low outgassing rate, comparable to SS, after high temperature bakeout, and has much higher electrical and thermal conductivities than SS. The structural members of the PWT assembly and the pressure chamber are made of SS, while the cavity endplates and disk are made of Class-1 OHFC copper. To better withstand the mechanical and thermal loaded stress, Glidcop, which has higher yield and tensile strengths than copper, may also be used. The supporting rods, and possibly the sieve are made of aluminium. The use of Al 6061 with high temperature bakeout will help maintain the UHV and at the same time increase the shunt impedance of the cavity.

To achieve UHV either SNEG coating or NEG strips, as illustrated in Figure 1, are mounted on the inner surface of the pressure vessel surrounding the PWT cavity. The NEG pumps are most efficient as their pumping speeds increase at low pressure. While best vacuum is achieved by brazing or welding the pressure vessel to the cavity, a non-removable pressure vessel would prevent the NEG from being replaced. To make the pressure vessel removable, we can use an inverted Conflat flange plus bellows, as shown in Figure 1. We have also considered an alternative pressure vessel design, adopting a technique commonly used in the microwave tube industry that allows the replacement of the cathode, using two short, thin-walled SS cylinders with wall thickness of 0.020 inch (see Figure 3), one brazed to the pressure vessel and the other brazed to the cavity back endplate, both at the cathode end, in such a way that one can slide one over the other with a with a minimum clearance so that the free ends of the cylinders can be heliarc welded together to form a vacuum.

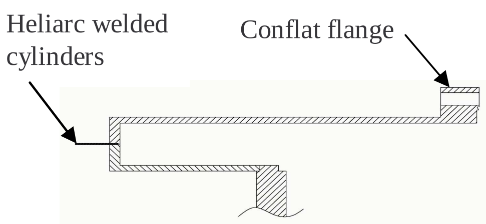

Figure 3: Heliarc welded design of the pressure vessel.

This heliarc welded joint can be opened (by machining or other way) and re-welded again several times before the cylinders need to be replaced completely; the number of times depends on the length of the skirt. To what extent the vacuum is degraded by a virtual leak that may form in the small gap between the two thin-walled SS cylinders needs to be investigated.

With a conservative outgassing rate of 7×10^{-9} Torr-L/s, a conductance of 1925 L/s from the cathode through the cavity and the sieve to the getter pumps that provide a pumping speed of 20000 L/s, the pressure at the cathode is 4×10^{-12} Torr.

THERMAL HYDRAULIC DESIGN

The heat loads on the cavity walls are higher under the CW operation of CEBAF than the pulsed operation of the ILC. About 60 kW of heat is distributed over the internal surfaces of the cavity that are exposed to RF, in proportion to the square of the magnetic field component perpendicular surface. Convective cooling is effectively accomplished by means of flowing water in channels inside the metals in three separate circuits. External control units (e.g. Neslab) are used to regulate the pressures and temperatures of the water. The heat in the endplates of the PWT is removed by water flow inside deep cooling channels embedded in the metal. The sieve is cooled by water flow in 48 longitudinal channels in a separate circuit.

The analysis methods comprise of finite element computer simulations using the COSMOS/M code, analytical calculations, MathCad/Excel worksheets and simple experiments to verify the flow and temperature distributions of the structure under CW operation. The calculation begins with the heat deposited in various components of the PWT cavity. At critical coupling and low beam loading, the total heat is equal to the square of the gradient of the accelerating field times the cavity length divided by the shunt impedance of the cavity. The heat distribution over the cavity surfaces is inversely proportional to the contributions of the Q-factor from various parts of the walls. The Q-factor contributed by each component in the cavity is calculated by setting the conductivity of all components to infinity *except* the component of interest in the EM simulations. The 3-D EM code, GdfidL, is used for the one-cell PWT frequency and Q-factor calculations.

Table 1: Heat loads on various components of the 1-cell PWT and flow rates needed to keep an average temperature of 40°C for the metals.

	Heat load (kW)	**Flow rate (LPM)**
Sieve	7.39	2
Disk	13.96	55
Rods	17.60	80
Front endplate	12.55	40
Back endplate	8.50	40
Total heat	60	

The temperature distributions as a function of flow rates are calculated using various finite element models of the disk, rods, sieve and endplates. Applicable heat loads from Table 1 are imposed on the outside surfaces of the models. Film coefficients on the wetted surfaces in the cooling channels are calculated based on the Reynolds numbers, Prandtl numbers and hydraulic diameters of the flow channels. Steady-state temperature distributions are obtained for given flow rates inside the channels. The flow rates are adjusted to obtain an average metal temperature that is about 20°C higher than the ambient. Table 1 summarizes the heat loads on various components and the flow rates (in liters per minute) needed to keep an average temperature of 40°C in the metals.

Figures 4 and 5(left) show the 2-D and 3-D temperature distributions of the disk and rods. Figure 5(right) shows the 2-D temperature distribution in the metal around one of the sieve conduits. Due to symmetry, only half of the conduit cross section is modeled. Figure 6 shows the 2-D temperature distributions of the front and back endplates.

The pressure drops in various parts of the circuits including orifices, pipes, channels, expansion and contraction losses are calculated using analytical formula [4]. Simple experiments were performed to verify the formula for orifices and straight pipes. The pressure drops of various parts were then included in flow network worksheets using the principles of flow continuity and Kirkoff's law to obtain the external pressure head. The required pressure head is in the range of 10 ~ 250 PSI.

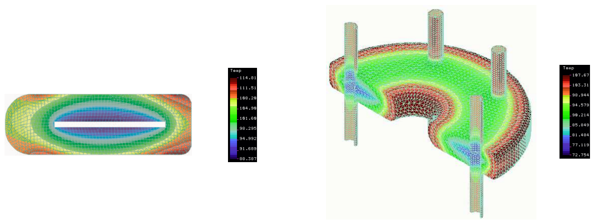

Figure 4: PWT disk temperature distribution (°F) from COSMOS/M 2D (left) and 3D (right) model.

Figure 5: Steady-state temperature distribution (°F) for rod (left) and sieve (right) from COSMOS/M 2D model.

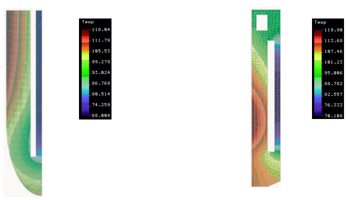

Figure 6: Steady-state temperature distribution (°F) for the PWT front endplate (left) and back endplate (right) from COSMOS/M 2D model.

RF AND FOCUSING MAGNET DESIGN

We have calculated and optimized the cavity parameters, i.e. frequency, R/Q and Q-factors, using 2D and 3D electromagnetic codes (SUPERFISH and GdfidL) for different design variants. Figure 7 shows the typical electric field maps of the 1-cell PWT. Based on a very fine mesh model with the SLAC EM code Omega3P [5], the Q-factor degradation of the PWT cavity has been calculated to be about 15% due to the presence of the slots in a stainless steel sieve.

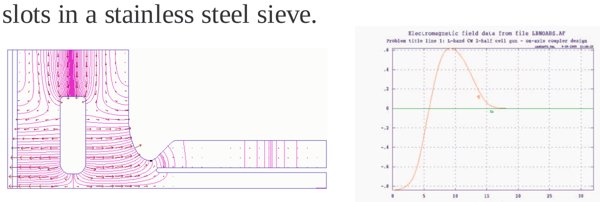

Figure 7: Electric field map from SUPERFISH.

The effect of slots on the Q degradation for an aluminum sieve is smaller, due to the much higher electrical conductivity and the relatively smaller contribution of the sieve loss to the total cavity Q-factor. Critical coupling calculations are performed using the Kroll-Yu method of moveable shorts [6], and checked independently using a perfect absorber in the waveguide. In view of limits of the numerical accuracies in these calculations, the resonant frequency and the coupling constant will be adjusted *in situ* during cold testing of the cavity. The coupling will be made critical by cutting the length of the inner conductor of the coaxial waveguide until the external Q is equal to the unloaded Q. The frequency will also be tuned *in situ* during cold test, by cutting the sieve to the proper length.

BEAM DYNAMICS SIMULATIONS

Beam dynamics simulations are performed using the ASTRA code. The ASTRA input parameters including injection phase and field magnitudes are optimized using the Cornell parallel processing code APISA which runs on multiple PCs. For these simulations, the initial bunch distribution is Gaussian in both longitudinal and transverse dimensions with charge per bunch=0.4 pC, bunch length=10 ps, and beam size=0.2 mm. Thermal emittance is included. The results are summarized in Table 2.

Table 2: ASTRA/APISA Simulation Results of CW PWT Gun with frequency = 1497 MHz, peak field = 6 MV/m

CW 1-cell PWT gun at 2m from the cathode	
Energy	280 keV
Normalized RMS Emittance	0.1 (mm-mrad)
Energy Spread	2.5 %
Bunch Length (rms)	40 ps
Initial Peak Current	40 mA
Beam Radius (rms)	0.8 mm
Peak Brightness	6×10^{11} A/m^2-rad^2

CONCLUSION

A room-temperature, continuous-wave (CW), 1497 MHz photoelectron gun using the Plane-Wave-Transformer (PWT) design can meet CEBAF injector parameters. Preliminary design and simulations have achieved excellent cooling, ultra high vacuum and low emittance.

REFERENCES

[1] G.A. Mulhollan *et al.*, Phys. Rev. Lett. A 282, 309 (2001).
[2] Dwersteg *et al.*, Nucl. Instr. Meth. A 393, pp. 93-95 (1997).
[3] P.A. Redhead, Found. Vac. Sci. Tech. 1998, p. 651.
[4] "Flow of Fluids Through Valves, Fittings, and Pipe" Crane Technical Paper No. 410; "Heat Transmission" by William H. McAdams.
[5] The Omega3P simulations were done by courtesy of C. Ng and K. Ko at SLAC.
[6] N. Kroll and D. Yu, Particle Accelerators, 34, 231 (1990).