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DESIGN AND FABRICATION OF A VHF – CW HIGH REPETION RATE ELECTRON GUN*

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Abstract

A high repetition rate, MHz, electron source is a key element in future FEL based light sources. The Advanced Photo-injector Experiment (APEX) at Lawrence Berkeley National Laboratory (LBNL) consists of a high repetition rate 186 MHz (VHF-band) CW electron gun, 1 MHz UV laser source, a pulsed 30 MeV linac, and the diagnostic components necessary to quantify the gun's performance. The gun design is based on well-established, conventional RF cavity design, with a couple notable exceptions. The basis for the selection of this technology, novel design features, fabrication techniques and measured cavity performance are presented.

INTRODUCTION

APEX (the Advanced Photo-injector EXperiment) is an electron injector based on a normal-conducting (NC) continuous-wave (CW) RF photo-gun at the Lawrence Berkeley National Laboratory (LBNL) [1-3]. The project was conceived as part of the R&D activities promoting the development of the Next Generation Light Source (NGLS) [4, 5] and now serves much the same function for the LCLS-II project at SLAC [6].

The goal that guided the development of the electron gun at APEX, to be referred to as the VHF Gun, was to produce a reliable CW, high repetition rate electron source with evenly spaced pulses and high brightness. For application to a Light Source user facility, the VHF Gun must be capable of continuous operation over periods of a week or longer with better than 99% availability. The guiding principal was to utilize proven technology and a conservative design approach. To maintain system design flexibility, the VHF Gun was initially designed to be compatible with either 1.3GHz or 1.5 GHz accelerating structures.

The selection of high quantum efficiency (QE) Cs_2Te photocathodes is compatible with current commercial UV laser technology and requires relatively modest 10^{-9} Torr vacuum levels. However, the goal for the VHF Gun is to provide an environment that is compatible with alkali antinomides cathodes which require an order of magnitude better vacuum. To address the issue of high brightness (low emittance) the gradient at the cathode of about ~20 MV/m was selected with a total accelerating potential of 750kV.

As reported previously, the shape of the cavity was tailored to produce the desired gradient and total accelerating voltage with less than 100kW of input power. Concurrently, multipactoring was minimized over a significant range of input power while maintaining surface power densities below 30W/cm2 [7]. The final design values are shown in the Table 1, below.

The choice of a VHF-band cavity has its origins in three factors. Firstly, the wall power density is a strong function of resonant frequency [8].

$$P_{wall} \propto f^{2.5} \quad (1)$$

Secondly, the relatively long wavelength allows high conductance slots to be opened in the cavity wall without causing a significant perturbation to the RF performance [9]. Thirdly, acceleration potential is effectively constant over the time scale of interest (< 60ps) while VHF operation provides a significant enhancement to the voltage breakdown limit, relative to DC conditions.

Table 1: A Partial List of VHF Cavity Parameters

Parameter	Value
Accelerating gap	40 mm
Frequency	187 MHz
Nominal gap voltage	0.75 MV
Electric field at cathode (at .75 MeV)	19.5 MV/m
Peak surface field (at .75 MeV)	24.1 MV/m
RF power for 0.75 MV	<100 kW
Peak wall power density at 0.75 MV	25 W/cm^2

KEY DESIGN FEATURES

The VHF Gun design represents a significant extension to some features found in previous RF accelerating cavities. To maintain a 10^{-10} Torr pressure during full power operation, an annular pumping plenum is contiguous to the cavity wall. The wall contains 104 11mm wide x 12mm deep x 110mm long pumping slots that provide a large gas flow conductance, ~7x10^6 l/s for hydrogen and 2x10^6 l/s for CO. Twenty 400l/s NEG pumps protrude into the pumping plenum and one 300 l/s ion pump is attached via a short bellows to provide a large pumping capacity.

The "anode" end of the cavity is joined to the body of the cavity by a metal to metal pressure contact. A canted spring ring, concentric to the contact surface provides a redundant current path. The cavity sections can be separated by grinding off a narrow, 3mm wide fusion weld. Once separated, the cavity frequency can be reduced by machining the coplanar stainless steel and copper contact faces on the anode end cap.

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All vacuum joints are either Ebeam welded, Ebeam brazed or TIG welded. The Ebeam braze joints at the end caps serve as a vacuum seal only. Mechanical loads (pressure, thermal and gravity) on both cavity end caps are resisted by bolted connections. An Ebeam welded/brazed assembly was selected for its reliability and ability to re-work without causing significant additional cost or delay. An added benefit is a significant reduction in the fixture complexity and preparation effort in comparison to furnace brazed construction.

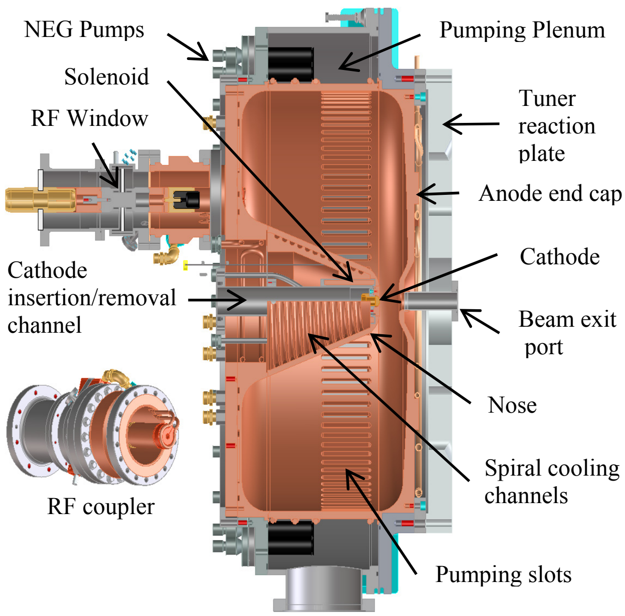
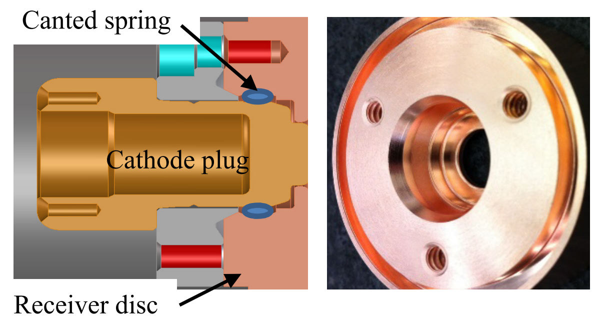


Figure 1: VHF Gun in cross section.

MATERIALS AND METHODS

As shown in Fig. 1, the gun is formed from five subcomponents; Cathode end cap, nose, cavity wall, anode end cap and vacuum wall. All cavity structures are fabricated from class 1 OFE (Cu10100) copper or class 2 material, when dimensions preclude availability of class 1 stock. Copper forgings were inspected using a standard ultrasonic NDE method to screen for voids and inclusions. The vacuum wall is fabricated from 304 stainless steel plate and commercial 304 stainless steel vacuum fittings and tube. The exception is the beam pipe at the exit of the RF cavity that is constructed exclusively from 316L tube and a 316LN vacuum flange to minimize the residual magnetic field at the cathode and along the beam path.

In operation, electrons are emitted from a Cs_2Te layer, or other low work function compound, on the surface of a polished molybdenum plug, an evolution of the INFN/LASA design. Agold plated, 304 stainless steel, canted spring ring on the plug's outer diameter provides the electrical connection to the receiver, Fig. 2a. A stepped radius on the plug and corresponding stepped bore in the receiver disk shield the spring contact region from the inner volume of the cavity. Because of the relatively delicate, precise features of this part it was fabricated separately from the remainder of the nose cone. This disk is roughly 50mm in OD and 10mm thick, Fig. 2b. A 4mm annular surface around the cathode opening on the cavity-side was machined to final dimension and finish prior to assembly in the nose. Areas outside of this inner annulus were "rough" machined with approximately 0.8mm of material left for a removal by a subsequent CNC vertical turret lathe operation.



(a) (b)

Figure 2a: CAD Model of cathode plug region, 2b: photo of cathode receiver.

The cathode receiving disk is Ebeam brazed to a precisely ground 316L stainless steel tube that is the channel through which the cathode passes between load lock and gun. The OD of the stainless tube accurately positions the fine wire solenoid that fits snuggly in the interior of the nose. This solenoid can be used to "buck" stray magnetic field from the focusing solenoid immediately downstream of the gun.

The re-entrant cavity "nose" is assembled from the center tube subassembly and a brazed two piece cone subassembly. The flanks of the nose absorb the highest power density, up to 25W/cm^2, of any location in the gun. To dissipate this heat, two parallel spiral cooling channels are milled into the surface of the inner cone. A close fitting outer cone blocks the majority of flow from bridging adjacent passages. Complete isolation of adjacent cooling passages is not expected or necessary. Braze joints, using a palladium-copper-silver alloy (PalCuSil15), between flat internal mating surfaces at the top (narrow end) of the cones and on a short precisely machined cylindrical segment at the base of the cones provide a hermetic seal. Both braze joints serve to isolate water from air and neither is exposed to the vacuum environment.

The cathode end cap is a water cooled structure formed by hydrogen furnace brazing two large circular copper plates together. Water passages machined into back of the inner (cavity side) plate are sealed against the flat-ground backing plate. Machining tolerances on these parts assure that mating surfaces have at most a 50 um clearance. To provide an adequate contact pressure for good braze filler wetting, large shallow pockets are machined into the inner plate between water channels

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thus reducing the contact area. A brazing fixture was constructed with molybdenum "draw" rods and copper "crush" washers to provide a compressive load at temperature without locally deforming the surfaces beyond the 0.8mm final machining allowance. A thick graphite "setter" plate assured that the assembly remained flat, Fig.3. Cooling tubes were brazed to the inner bore of the end cap in the same operation.

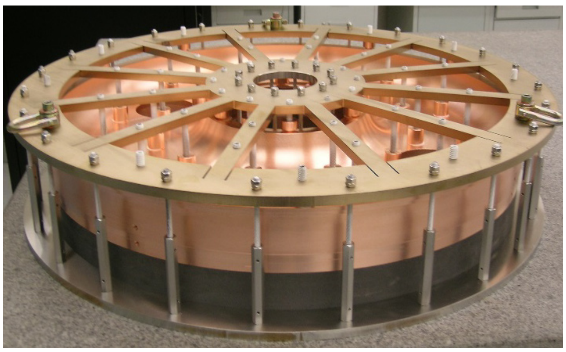

Figure 3: Cathode end cap in brazing fixture.

To complete the cathode assembly, the central tube/disk subassembly is placed flush with the nose surface and a 6mm deep Ebeam fusion weld is made between the close fitting disk and precisely bored cone. The base of the cone is then Ebeam welded to a raised face on the cathode end cap providing both the vacuum and mechanical connection, Fig. 4.

Figure 4: Cathode assembly after Ebeam welding.

The cavity wall is constructed from ¼ hard copper plate, rolled and TIG welded to form a cylinder. Copper cooling tubes are TIG fusion welded to the wall. Through trial and error, a specifically shaped feature was found that, when machined into the wall's outer surface, provide for a reliable weld that does not breech the cooling tube wall and provide sufficient thermal conduction without annealing the bulk of the cavity wall. In operation, a 3mm x 0.25mm tall rim on the face of the cavity wall bears against a flat surface on the anode end cap to form the high current contact.

In contrast to the cathode, the anode end cap is constructed by TIG brazing copper cooling tubes to the exterior surface. This operation does not anneal the bulk of the copper which is significant since annealed copper

Figure 5: Fusion weld of cooling tube to cavity wall.

may not provide an adequate contact force for the high current electrical connection. The base of the cavity wall, with tubes attached, is Ebeam welded, using a 6mm deep penetration, to the cathode end cap. After welding, the internal surfaces of the cathode end cap, the nose and the base of the cavity wall are machined as a unit to final dimensions.

The exterior surface (air-side) of the copper anode plate is ground to be coplanar with the surface of the adjacent stainless steel flange. The structural support for the copper anode plate is provided by the flange through a bolted connection to a stainless ring that overlaps both surfaces. Similarly, the copper portion of the cathode end cap is match machined and bolted to a flanged stainless steel ring. Subsequently, the vacuum seal for both end caps is formed by fusing a 3mm tall copper ledge with the interior surface of the adjacent stainless steel flange. Once the cathode and anode bores are aligned to within 25um, the final vacuum seal is made by TIG welding the joint between vacuum wall and anode flange.

To date, the VHF Gun has reliably achieved stable operation at full energy and a 1 MHz pulse repetition rate for many days at a time [3]. Measurement of the transverse and longitudinal emittance awaits full implementation of APEX. Two papers on recent experimental results of APEX are presented in this conference [10,11]. Commissioning of the transverse emittance diagnostics has started and preparations for a full characterization of the gun are underway [12].

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