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STATUS OF THE MAGNETIZED THERMIONIC ELECTRON SOURCE AT JEFFERSON LAB

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Abstract

A 125kV DC gridded thermionic gun has been designed and constructed through a collaboration between Jefferson Lab and Xelera Research LLC. The gun has been recently installed at the Gun Test Stand diagnostic line at Jefferson Lab where transverse and longitudinal parameter space will be experimentally explored. The status and results characterizing the commissioning and trouble-shooting the thermionic gun are presented.

INTRODUCTION

The Jefferson Lab Electron Ion Collider Design includes a bunched beam cooling scheme to improve the luminosity of the ion beam [1]. The cooler injector requires an electron beam with beyond state-of-the-art properties, listed in Table 1. Furthermore, the beam must be magnetized by immersing the cathode inside a solenoid. The magnetization is removed from the beam as it enters the fringe of the cooling solenoid, where it co-propagates with the ion beam providing cooling. A magnetized beam has a correlated emittance component, and this is chosen specifically to be matched into cooling solenoid. The 36um correlated emittance is achieved through balancing the emitting area with the magnetic field in which it sits.

Table 1: JLEIC Cooler Injector Parameters

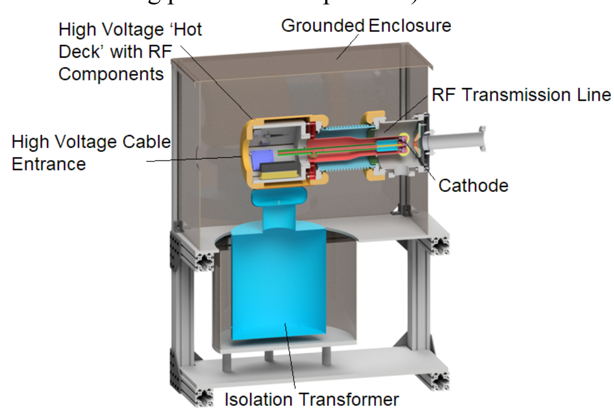
Parameter	
Bunch charge	3.2nC
Bunch repetition rate	43.3MHz
Injector Energy	5-7Mev
Uncorrelated transverse emittance	<10µm
Correlated (magnetized) emittance	36µm

The baseline design for the cooler injector invokes a multi-alkali photocathode inside an RF gun [2]. The combination of bunch charge and average current are demanding constraints for the typical photocathode. Thermionic cathodes are known for being robust, maintaining long lifetime and delivering high average current (several Amps). However, the technological know-how in the accelerator community has been somewhat lost since the advent of photocathodes which can provide well-tailored bunch shape and extremely low thermal emittance.

As a back-up to the RF photoinjector, DC photogun [3] and a thermionic DC gun are being investigated. On the research path towards a 500kV thermionic DC gun, Xelera Research LLC and Jefferson Lab are designing and testing a 125kV DC, thermionic gun. The JLEIC cooler design requires bunched beam, so the thermionic cathode must be modulated whilst simultaneously delivering a good quality beam with low transverse emittance and small energy spread.

THE ELECTRON GUN

The electron gun, shown in Fig. 1, is designed to deliver a maximum of 65mA beam at 125kV. The gun specifications can be found in Table 2. The electron emission is modulated at 500MHz, chosen to be compatible with JLab components, and can produce 130pC CW (higher could be achieved using pulsed mode operation).



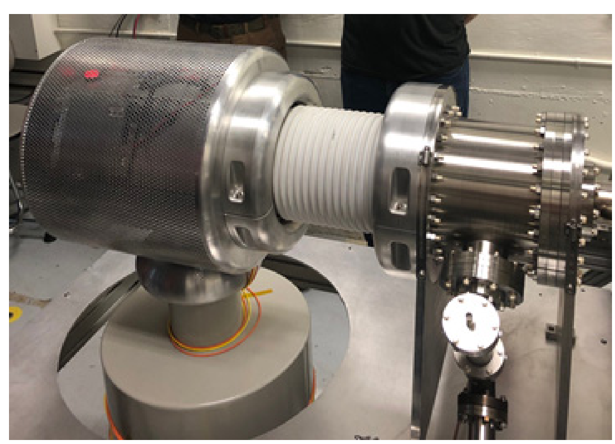


Figure 1: Thermionic gun (top) model, (bottom) as built.

The gun employs a commercial off-the-shelf thermionic cathode, which is gridded, as shown in Fig. 2. Applying a positive voltage to the grid with respect to the cathode, results in electron emission. In the geometry of this gun, the grid is connected to the potential of the cathode electrode

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at -125kV, and the emitter is modulated relative to this to gate the electron bunches.

Table 2: Thermionic Electron Source Design Features

Parameter	
Max. Average Current	65 mA
Nominal gun Volt	125kV
RF Frequency	500MHz
Cathode	CPI Y-845
Nominal bunch charges	130 pC
Cathode/Anode Gap	26 mm
Cathode Angle	20 deg
Anode Angle	31 deg
Transverse Emittance	4 µm at 130 pC
Correlated (magnetized) emittance	36µm

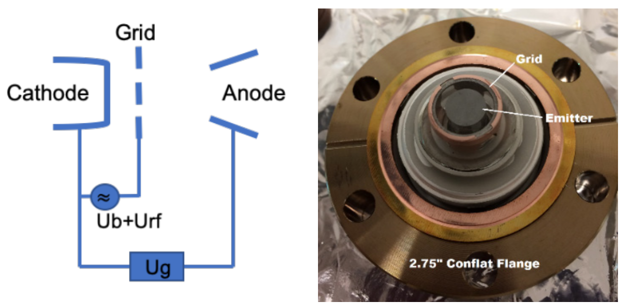

Figure 2: (left) Gun electrical diagram, Ub: bias voltage, Urf: RF voltage, Ug: Gun voltage. (right) Gridded cathode (CPI Y-845).

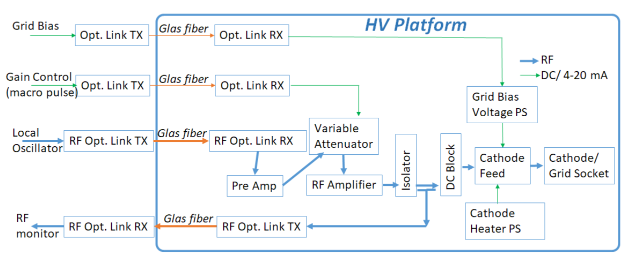

Figure 3: RF Cathode and grid drive design.

The electronics to control the 500MHz RF and DC bias on the emitter sit atop an isolation transformer ('hot-deck'). The electronic scheme is shown in Fig. 3. A power supply heats the emitter and a second applies a positive DC bias to the emitter to suppress emission. When a RF voltage is added to this bias, and the superposition is less than the cut-off voltage, electrons are accelerated by the electric field between cathode and anode electrodes inside the gun, illustrated in Fig. 4.

The RF+DC bias connects to the back of the cathode assembly with a matched RF transmission line. The hot-deck is controlled via fiber optic links that supply the fundamental RF at 500MHz. There is an amplifier on the hot-deck to provide the full RF voltage required for emission. The DC bias setting is remotely controlled and a macro-pulse modulator signal is also sent via fiber link. The macro-pulse cuts the RF signal to within a window to reduce the average current to protect diagnostics.

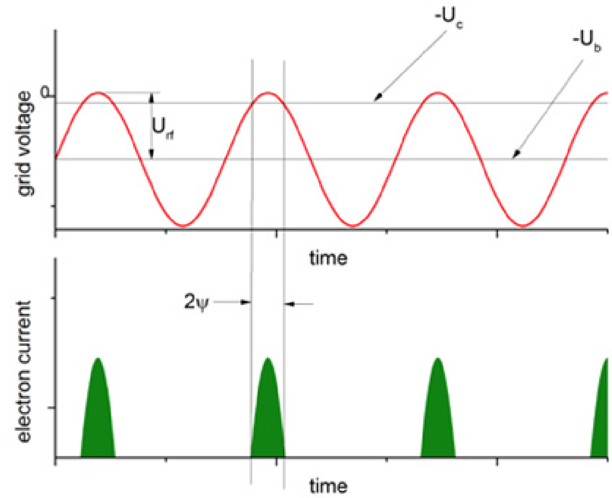

Figure 4: Voltages applied to the grid (top). When this exceeds the cut off, Uc, emission occurs (bottom).

DIAGNOSTIC BEAMLINE

The 4m diagnostic beamline downstream of the gun contains a series of solenoids and steering magnets to guide the beam to diagnostics and the dump, shown in Fig. 5.

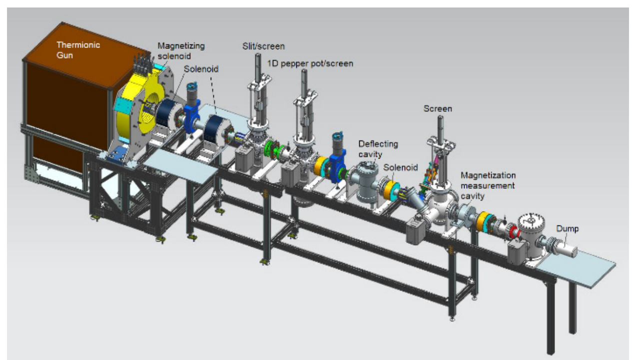

Figure 5: Diagnostic beamline.

Immediately after the gun is a large magnetizing solenoid that provides a longitudinal field over the cathode emitter. Downstream, the diagnostic suite includes screens, slits, a 1D pepper pot, transverse deflecting cavity, magnetization measurement cavity [4] and Faraday cup. The slit is used in conjunction with a screen to determine the magnetization of the beam by looking at the rotation of the beamlets. The slit-screen emittance measurement technique can also be used to reconstruct the transverse phase space of space-charge dominated beams and calculated the rms effective transverse emittance [5]. A 1D pepper pot has been designed specifically with the purpose of improving the accuracy of longitudinal bunch profile measurements with the transverse deflecting cavity [6]. Additionally the 1D pepper pot can be utilized to measure the uncorrelated portion of transverse emittance in both planes [7].

COMMISSIONING RESULTS

After delivery of the gun assembly in July 2019, testing of the hot deck began. All transmissions to the hot deck via the fiber optic links have been verified. The fiber optic link

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pair for the macro-pulse signal which chops the 500MHz pulse train will be upgraded as the rise time of the pulse is 20µs with the analog links, as shown in Fig. 6. The shortest pulse required to protect view screens is 50ns. A digital fiber link with a faster sampling rate will decrease the rise time of the signal.

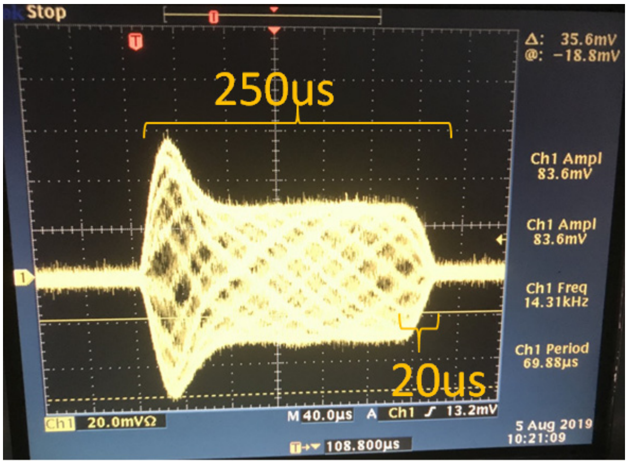

Figure 6: 250µs macro pulse signal measured at the hot deck.

The gun is being high voltage conditioned at the moment, whereby field emitters are eliminated and the gun can be at 125kV without producing vacuum bursts or radiation. On arrival the gun had good vacuum, in the mid e^{-10} Torr range, but during processing there were vacuum bursts that would trip the high voltage power supply (suspected desorbed water). The gun was baked at 150C over 4 days, and afterwards, although the baseline vacuum was much the same, the processing was then dominated by field emitters rather than vacuum events. Initially, field emission onset was found at 90kV. Typically guns are processed with some overhead to the baseline voltage, but there was significant current draw and radiation signals at 140kV. The maximum power supply voltage of 150kV did not apply enough gradient for this field emitter to be processed away. Krypton processing is now being implemented to reduce field emitters via bombardment with ionized Kr, as this has been successful with several higher voltage DC photoguns at JLab [8].

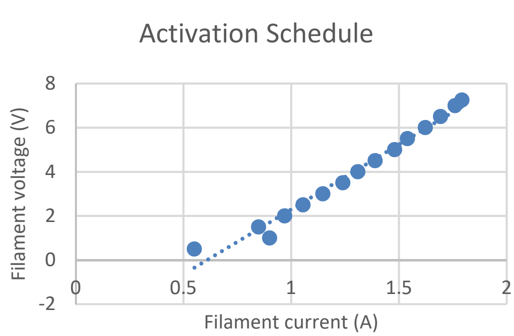

Figure 7: Plot of cathode activation.

The cathode arrives under vacuum and must be activated before use. This is a process of gradually increasing the voltage to the cathode heater filament, whilst maintaining a vacuum of <1e^{-7} Torr, as shown in Fig. 7. This took around 4 hours to complete and emission was verified by applying a voltage to the grid.

OUTLOOK

The commissioning phase of the thermionic electron gun is nearing a close. Left to complete is the high voltage processing and matching the RF transmission line to the cathode. The diagnostic beamline is complete, under vacuum, and poised ready for the next phase of electron beam measurements.

Jefferson Lab will continue to partner with Xelera Research LLC to secure funding for a higher voltage thermionic gun that meets the specification of JLEIC Cooler beam.

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