Troubleshooting and Characterization Of Gridded Thermionic Electron Gun

M. Stefani, F. Hannon

Old Dominion University, Electrical and Computer Engineering

Thomas Jefferson National Accelerator Facility, Newport News, VA 23606 USA

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Thomas Jefferson National Accelerator Facility

Abstract

Jefferson National Laboratory has, in collaboration with Xelera research group, designed and built a gridded thermionic election gun with the potential for magnetization; in an effort to support research towards electron sources that may be utilized for the electron cooling process in the Jefferson Laboratories Electron Ion collider design. Presented here is the process and result of troubleshooting the electron gun components and operation to ensure functionality of the design.

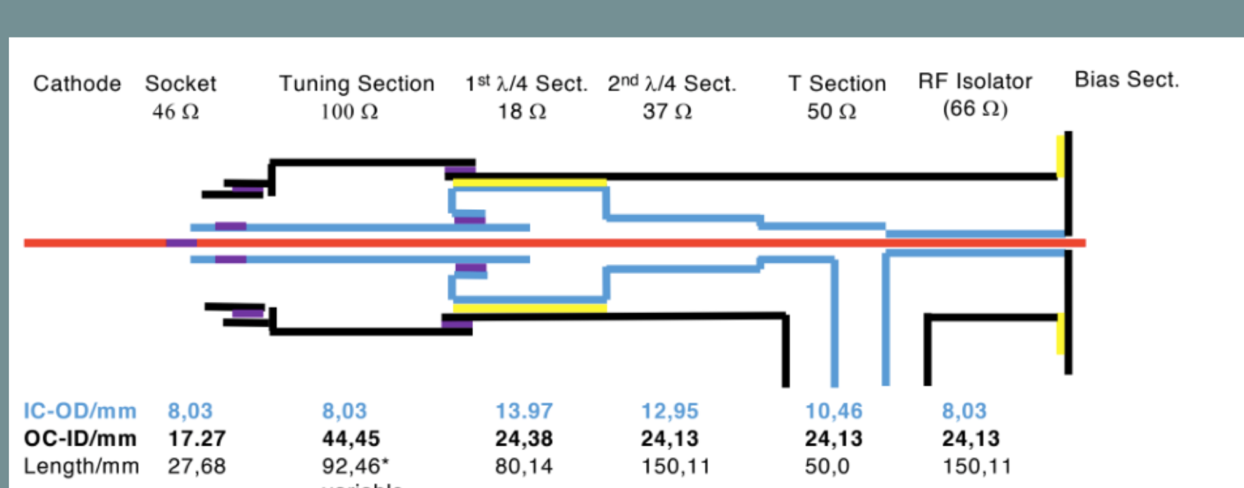
Overview of Gun Configuration & Operation

The overall design goals were to build a gridded thermionic gun, operating at 125 kV with a frequency of 500 MHz, and a variable bunch charge with the nominal bunch charge being 130 pC. The gun must also be able to macro pulse the bunch train to control the average current. The standard operation of a gridded thermionic gun produces electron bunched by heating the cathode emitting surface via a current producing resistive heating, applying a sufficient bias voltage to the nearby grid to prevent electron emission and then superimposing a RF voltage to the bias on the grid to periodically reduce the local gradient and allow for electron emission. [1,2]

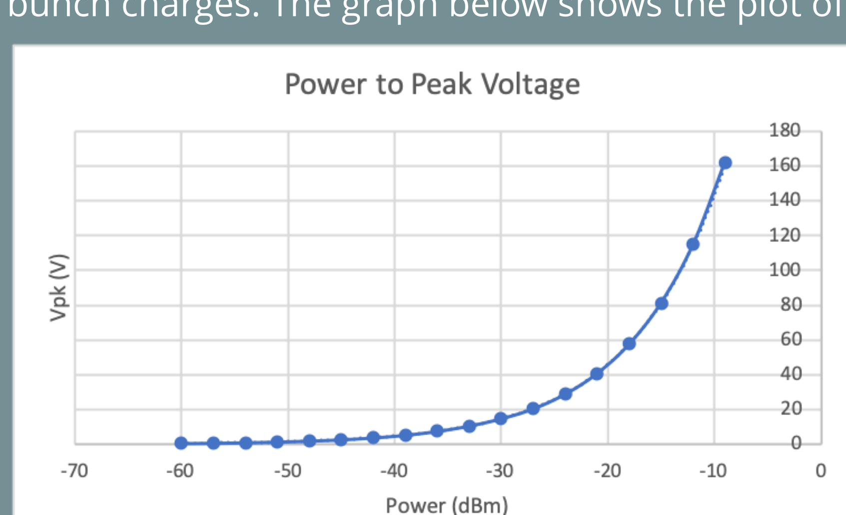
The design of our gun however superimposes all of these DC and RF signals onto the cathode surface, as well as the high voltage (HV) applied to the cathode electrode.
By applying HV to the electrodes, controlling the bias and RF power to produce electron bunches from the gridded cathode, and using the macro pulsing signal to the pin modulator, this design should be able to produce all the design characteristics. The following sections of this paper should clarify the operations of each component mentioned and the method of troubleshooting used to establish functionality.

RF Components

Below is a general schematic of the transmission line. An important design feature is the inner conductor diameter increasing in steps from the back of the transmission line where the DC bias and current are introduced. The larger inner diameter will have a lower impedance for the RF signal and therefore channel the RF signal forward towards the cathode. The back plate where the DC bias and current are introduced is electrically isolated from the outer conductor of the transmission line by a kepton gasket. The contact for the grid at the cathode contacts the outer conductor of the co-axial line and this ensures that the grid is locally grounded to the rest of the hot deck's potential.



Troubleshooting of the transmission line and all other RF components was perform in sequence starting from the RF generator all the way through the system using an oscilloscope with a fast-enough sampling rate and a power meter to measure the frequency, power and peak voltage. The peak RF voltage is needed to calculate the predicted bunch charge given a specific bias voltage. Therefore, the peak voltage had to be plotted against input power to gain a relationship needed to later control the gun's bunch charges. The graph below shows the plot of these measurements.



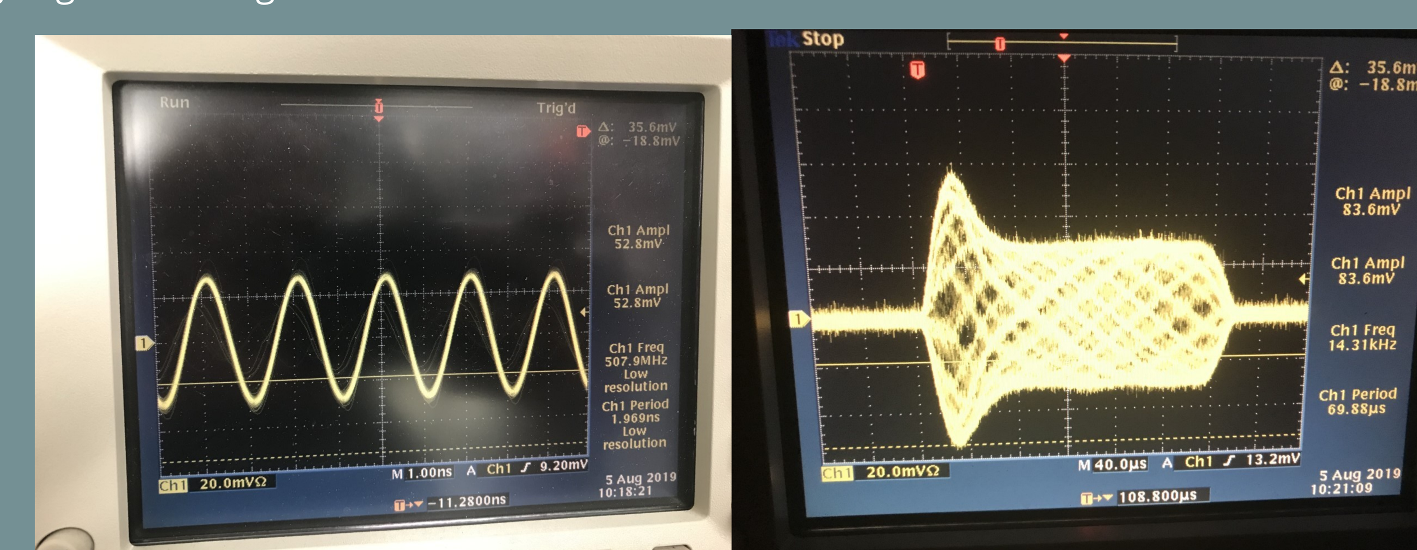
DC Bias & Heater Current

The DC bias and heater currents are the most straight forward components to troubleshoot. Firstly, the fiber optic remote control of the bias voltage needs to be tested. At the time of purchasing the power supply, it was unknown that the internal positive sense pin is connected to the common of the remote-control voltage for our specific supply. This has the effect of only allowing a negative bias when the power supply is remotely controlled. It is important to be able to have both positive and negative bias control and this is therefore a issue that needs to be addressed. Apart from this complication, the negative output voltage does indeed scale linearly from 0-320 V from the 0-10 V signal form the analog fiber optic transceiver.

The current supply in our system does not have the capability of remote control as this is a value that is typically set to achieve a desired operational cathode temperature and then left at those value for the entirety of the operation. Simply measuring the voltage and current reading with a multimeter confirms this components operation. It is worth noting that remote control of this component would be beneficial in future gun designs as the resistance of the cathode heater increases with temperature and therefore the voltage on the current supply must be manually stepped up to operating temperature to prevent the supply going into a current limited mode which prevents the cathode from reaching operating temperature. The most important aspect of troubleshooting these components is to connect them to the RF transmission line, test that their combined output is electrically isolated from the outer body of the transmission line and test that the voltage difference from the back-contact plat and the body has the same value as the bias voltage and that the current and voltage across the back plate contacts are equivalent to the output of the current supply. If these three conditions are met the DC components of the gun operation are functional.

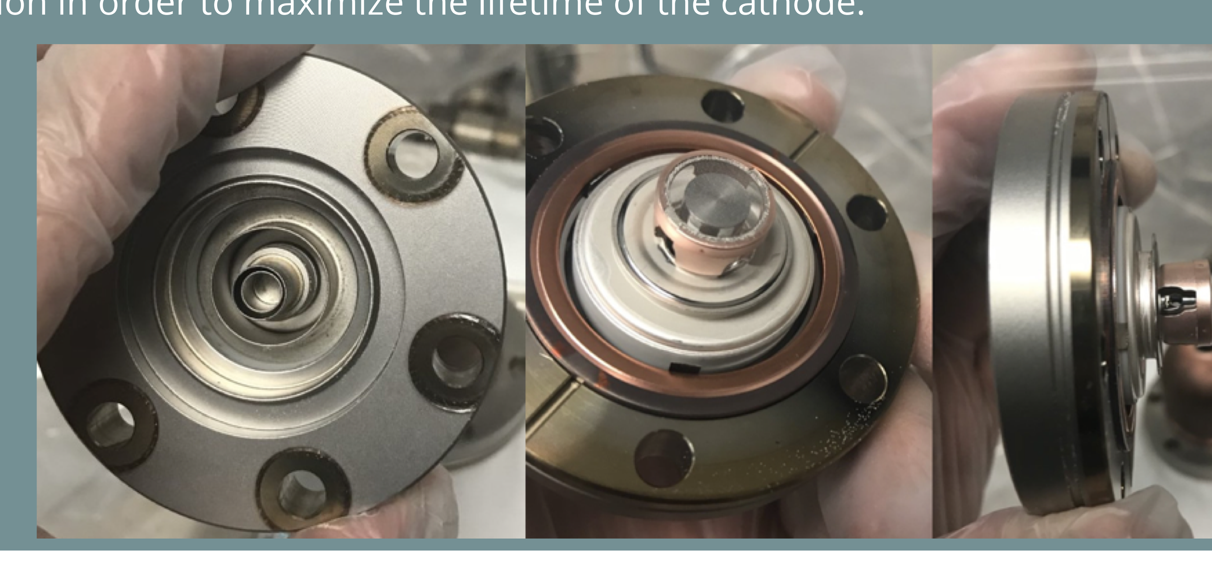
Fiber-Optic Macro-Pulsing

This macro pulsing operates by using a 5V signal with a temporal length set by epics software depending on the mode of operation. The modes are continuous wave (CW), a condition which would be a non-pulsed bunch train, tune mode which is a pulsed 5V signal 250 micro seconds in length, Viewer limited mode which is typically 4 micro seconds in length, and user mode which has variable frequency of signal and length down to 50 nanoseconds. The troubleshooting of this system is performed using an oscilloscope to first check the 5 V pulse from the epics software and the resultant RF signal produced at the output of the RF pin modulator. The two images below show the standing CW output and the envelope of the tune mode pulse. The tune mode pulse has a troublesome "ringing" from the leading edge and further issue with rise and fall times. The rise and fall times both being 20 micro seconds indicate that viewer limited mode is not operational as the rise time is 5 times larger than the entire viewer mode signal. This is indeed the case, as there is no signal on the oscilloscope when in viewer limited mode. It was determined that the fiber optic transceiver sampling rate is not fast enough to detect the epics software signal at these timescales. A faster digital fiber-optic transceiver was required with a much fast sampling rate and faster response time to leading and trailing edges of the signal.



Cathode Isolation & Activation

shown here is the back of the cathode assembly comprising concentric rings, the front of the cathode with the grid, cathode surface, and heater element of the CPI Y-845 cathode used in the thermionic gun. The activation process is necessary to remove oxidation and allow for outgassing of any contaminates. The process involves increasing the voltage to the heater element in small intervals over a period of 3 hours to slowly bring the cathode up to an operational temperature (around 1100 C). The time in between steps is necessary to allow outgassing to take place slowly and to prevent the cathode form being exposed to any vacuum higher than $1e-7$ Torr once activation begins. Above this pressure, the surface can be poisoned. Effectively impeding electron emission from the surface. Once the cathode is brought up to operational temperature, and all outgassing has subsided, a small bias voltage around 3 V is applied to induce electron emission. Emission current from the cathode passing through the grid is measured by the bias supply. For activation, 150 mA of current is desired for 15 minutes. After this time, the bias voltage is left at the same value while the voltage from the current supply is lowered until a drop in emission is seen. This determines the operational voltage/current and therefore operational temperature. The applied voltage should be the minimal value that does not inhibit emission in order to maximize the lifetime of the cathode.



Future Procedures for Characterization

The next steps in commissioning and troubleshooting are determining the values of the emission cutoff voltage for a given HV and establishing the transconductance of the gun from the slope taken from the plot of current as a function of bias voltage. Knowing the cutoff voltage and transconductance allows us to control the bunch charge by varying the DC bias and RF peak voltage. The properties of these bunches such as bunch length and emittance will be measured, and finally a high current magnetized beam will be produced by establishing a magnetic field perpendicular to the cathode surface by a large solenoid near the cathode. The Lorenz kick form the magnetic field imparts an angular-momentum to the electron beam. These angular-momentum dominated beams are referred to as magnetized beams [3].

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