ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLS10

TROUBLESHOOTING AND CHARACTERIZATION OF GRIDDED THERMIONIC ELECTRON GUN

M. Stefani*, Old Dominion University, Dept. of Electrical & Computer Engr., Norfolk, VA, USA
F. Hannon, Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

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 AND 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. This design requires that the RF components, RF transmission line, bias voltage supply, and heater current supply all be lifted to the 125 kV by an isolation transformer allowing 110 AC power to these components while they have a new local "ground" potential of 125 kV. The controls for these components are then communicated via fiber optic cables. The bias voltage is remotely controlled by an analog fiber optic transceiver that has an output of 0-10 V. The supply then linearly scales this input to a 0-320 V output. This bias supply output is used to float the current supply voltage. The current supply then contacts the electrically isolated cathode heater and emitter via the center conductor of the co-axial RF transmission line; having the effect of allowing resistive heating while also establishing a stable bias voltage on the cathode compared to the grid which is locally grounded via the outer conductor of the co-axial RF transmission line. Therefore, the necessary gradient is present between the grid and cathode to restrict emission. The RF signal is transferred from the RF generator to the components at HV (collectively called the "hot deck") via RF to RF fiber optic transceivers. The RF signal once sent to the hot deck then goes through a low noise amplifier and then must pass through a pin modulator which allows the macro pulsing. The pin modulator is also controlled via fiber optic signal. A 5V signal is sent to the pin modulator from a digital fiber optic transceiver and when this 5 V signal is present the pin modulator passes the 500MHz RF signal to a 50-Watt amplifier on the hot deck. After the amplifier, a RF isolator is present to protect the amplifier form any reflected power. Then the RF is sent through a Bi-directional coupler used to pick up the reflected power which is needed to match the RF transition line by minimizing the reflected power. The forward power from the bi-directional coupler is then passed through a DC blocker, so that the DC signal on the center conductor do not back-feed into the RF system. Finally, the RF is sent into the co-axial transmission line by a SMA connection that functions as an RF bias-T. Thus, the RF signal, The bias voltage and the heater current are all carried to the cathode via the RF transmission line.

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

This section will more clearly detail the RF transmission line design and functionality. Figure 1 gives a general schematic of the transmission line.

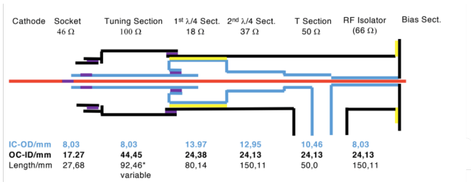

Figure 1: RF transmission line schematic.

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-

---

* mstefani@jlab.org

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-TUPLS10

axial line and this ensures that the grid is locally grounded to the rest of the hot deck's potential.

There is a comparatively large chamber that slides like a trombone that is used to match the impedance of the cathode for the RF signal. As mentioned earlier this matching is achieved by minimizing the reflected power. The tuning section length is adjusted by three screws facing the back of the transmission line.

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. Figure 2 shows the plot of these measurements.

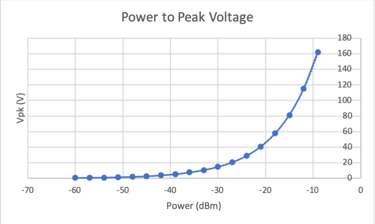

Figure 2: RF generator power to peak voltage.

Eq.1 is derived from the fit of this plot allowing us to set the power of the RF generator to give a required peak voltage desired for a given bunch charge.

$$P_{in} = \frac{1}{0.114} ln\left(\frac{V_{pk}}{450}\right) \tag{1}$$

FIBER-OPTIC MACRO-PULSING

The ability to macro-pulse the RF signal, effectively pulsing the electron bunch train to limit average current, is vital for future work in characterizing electron beam produced by the gun. The diagnostic beamline uses YAG screens both for steering and measurement and we must therefore be able to limit the incident current on the screen even with bunch charges of 130 pC. 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. Figure 3 shows the standing CW output and Figure 4 shows 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.

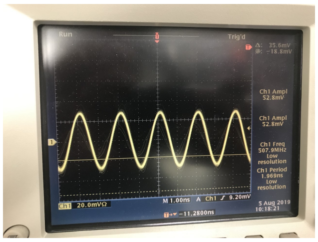

Figure 3: CW 500 MHz signal at RF output.

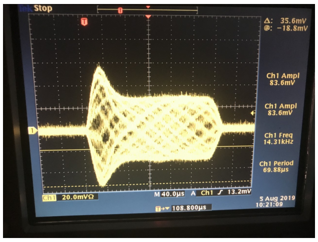

Figure 4: Signal envelope of macro pulsing in tune mode.

DC BIAS AND 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.

CATHODE ISOLATION AND ACTIVATION

This section details the components of the CPI Y-845 Cathode used in the thermionic gun, how each aspect of the cathode assembly is isolated, and contacted by components of the RF transmission line. Finally, the activation and troubleshooting of the cathode is discussed.

Figure 5 shows the back of the cathode assembly comprising concentric rings and shows the front of the cathode with the grid, cathode surface, and heater element. Each ring in Fig. 5 is associated with the heater, the emission surface and the grid. The heater and emission surface connect in series allowing for the two inner rings to create a closed circuit from the current supply "in" through the heater element and "out" through the emission surface, back to the common pin of the supply, closing the circuit. The third ring is associate with the grid and is electrically isolated by ceramic. The RF transmission line was designed for inner conductor carrying the bias and current to contact the two inner rings and the body of the transmission line to contact the outer ring effectively grounding the grid. Again, this allows for the local potential difference between the grid and cathode surface be controlled by the bias and RF signal that repress or allow for electron emission from the surface of the cathode.

Figure 5: Left: cathode back contacts. Middle: cathode grid and emitting surface. Right: visible heater element.

The activation process is necessary to remove unwanted oxidation and allow for outgassing of any possible 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.

It is worth noting that we decided to HV process the thermionic gun before the activation process.

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].

ACKNOWLEDGMENTS

Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.

REFERENCES

[1] F. Ames, *et al.*, “The TRIUMF ARIEL RF modulated electron source”, in *Proceedings of EIC14*, Newport News, VA, USA, 2014.

[2] R. Bakker, *et al.*, “1 GHz modulation of high-current electron gun”, *Nuclear Instruments and Methods in Physics Research A*, vol. 307, pp. 543-552, Oct. 1991.

[3] Y. Sun, P. Piot, “Summary of The Angular-Momentum-Dominated Beam Experiment”, JLAB, Newport News, VA, USA, 2004. `http://wiki.jlab.org/ciswiki/images/0/0b/MagBeam_Y.-E.Sun-AprilMay2004.pdf`