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STUDYING THE EMISSION CHARACTERISTICS OF FIELD EMISSION CATHODES WITH VARIOUS GEOMETRIES*

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Abstract

The cathode test stand (CTS) at LANL is designed to hold off voltages of up to 500 kV and can supply pulse durations up to 2.6 µs. We are able to test both field emission and photocathodes with different geometries and materials at various pulse lengths and pulse-forming network (PFN) voltages. Currently, the test stand is used to evaluate field emission using a velvet cathode over various pulse lengths. The CTS employs various diagnostic tools, including E-dots, B-dots, and a scintillator coupled with a pepperpot mask in order to measure the extracted voltage, current, beam distribution, and transverse emittance. Trak has been used to create and simulate diode geometries, providing potential to study and optimize various beam parameters. These geometries include changing the size and recess of the cathode as well as implementing a Pierce geometry. Here, we will discuss comparisons for various simulated cathodes and how changes in geometry impact given beam parameters. We also show preliminary results taken with the CTS and discuss the relationship between the results and the simulated data.

INTRODUCTION

A thermionic cathode is used to create a long electron beam pulse on the Dual Axis Radiographic Hydrodynamic Testing facility (DARHT) Axis II, which is programmatically kicked into four smaller pulses [1]. The thermionic cathode has drawbacks, one of which being it must be heated to a suitable temperature for the electrons to overcome the work function of a material. A field emission cathode is favoured, as it does not require a heating source. Instead, applying an external electric field onto the cathode with a low work function extracts the electron beam. These cathodes, also known as cold cathodes, are already used in several other facilities, including DARHT Axis I [2], for radiographic purposes. However, these pulses are relatively short in comparison to the 1.7 µs pulse produced by Axis II [1]. The purpose behind the Cathode Test Stand (CTS) at LANL is to evaluate field emission cathodes across long pulse durations as an eventual replacement for a thermionic cathode.

This write-up will describe the design and set-up of the CTS, including a description of all employed diagnostic devices. We then discuss simulations created using Trak [3]. These simulations revolve around changing the cathode recess and examining the extracted current and 4rms emittance at a given diode voltage. We also show experimental measurements at a variety of charges on the PFN. These measurements will be compared and evaluated against the data collected from the Trak simulations. Finally, simulations for a cathode plug utilizing a Pierce geometry will be shown and the extracted parameters described.

EXPERIMENTAL SETUP

The CTS, designed to hold off voltages up to 500 kV, utilizes a PFN capable of providing a 2.6-µs-long pulse up to 400 kV and a crowbar which can reduce the pulse length to 0.3 us. The cathode is a 15-mm-diameter velvet cloth stretched on an aluminium holder. The cathode is recessed 3 mm into the shroud, and the AK gap is held at 22 mm. Both the cathode and anode shrouds are composed of polished stainless steel.

Voltage measurements in the diode are made using capacitive E-dots probes, one of which is numerically integrated, and one hardware integrated. An additional voltage measurement is made with an E-dot near a ballast resistor. Current measurements are made using several B-dot probes: a differential B-dot in the diode and a Beam Position Monitor array consisting of four differential B-dots. Figure 1 shows the design of the CTS and the locations of the diagnostics.

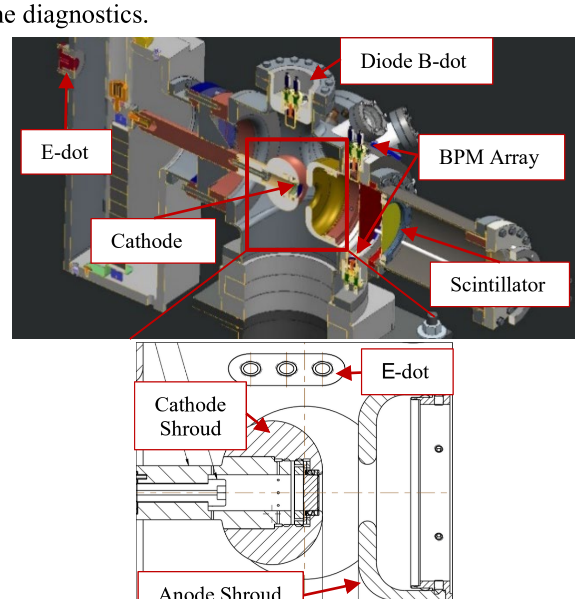

Figure 1: Design of the CTS.

An 87.6 mm alumina scintillator is used to measure the beam current density and spatial profile. This is designed such that it moves between 71.3-131.3 mm from the cathode shroud. Image intensified gated CCD cameras are utilized for cathode and scintillator imaging [4]. Each camera

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provides a 16-bit image and is programmed to have a 10 ns gate, where the gating times are moved for various shots. Additional scintillator imaging is performed with a Simacon fast-framing camera, which consists of 8 individual ICCDs, each capable of taking two 12-bit images. Images are taken with a 100 ns gate width and no interframe delay.

SIMULATIONS

Trak [3] is a particle orbit tracking code which uses electromagnetic fields generated by finite element electromagnetic codes. Using Trak, the geometry in the CTS is simulated. The software then provides calculated beam parameters for a given diode voltage, such as the extracted current and emittance. For a diode voltage of 250 kV, the extracted current was 91 A and the 4rms emittance, measured at location Z = 10 cm, was 67.8 pi-mm-mrad[1].

The program was also used to obtain information on how the recess effects the extracted current and measured 4rms emittance. Figure 2 shows the relationship between the cathode recess and both the extracted current and 4rms emittance. As the recess is increased, the extracted current decreases, which is in good agreement with the works of Plewa et al. [5]. This work shows that this decrease is characterized by a fourth order polynomial function. The emittance shows an initial decrease, with a slight increase after the 3 mm recess.

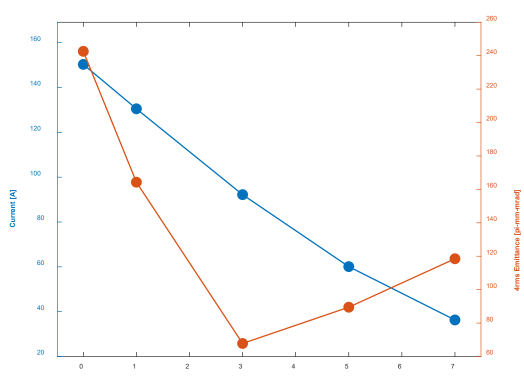

Figure 2: Extracted current and 4rms emittance at different cathode recess values.

EXPERIMENTAL MEASUREMENTS

Varying Operating Voltage

The CTS operates at several different operating voltages. Measurements are taken at a 50 kV, 60 kV, and 70 kV PFN charge. An increase in the supplied charge corresponds to an increase in diode voltage and extracted current. The supplied voltage increase also corresponds to an increase in measured pulse length and a decrease in rise time on the current waveform. Figures 3 and 4 show voltage and current waveforms for shots taken with a 700ns crowbar at different charges on the PFN. Shot 7086 is taken with a 50 kV charge, shot 7116 with a 60 kV charge, and shot 7128 with a 70 kV charge. The 50kV charge corresponds to an approximate 170 kV diode voltage, the 60 kV a 200 kV diode voltage, and the 70 kV a 240 kV measured diode voltage.

The current waveforms consist of stochastic peaks throughout the pulse. These occur in most pulses and their intensity is independent of diode voltage. The source of these irregularities is unknown and under investigation.

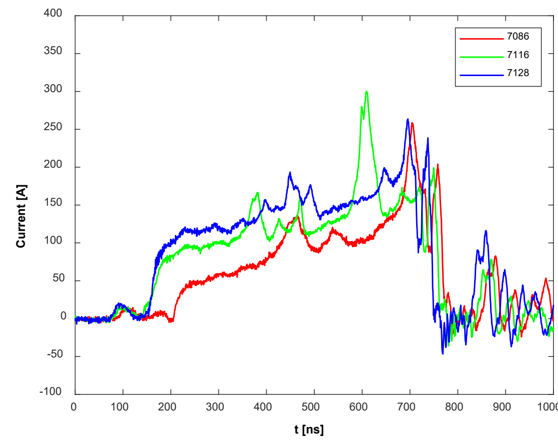

Figure 3: Extracted current throughout a 700 ns pulse.

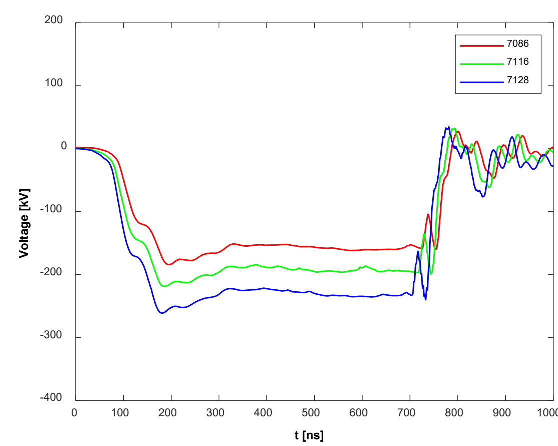

Figure 4: Diode voltage throughout a 700 ns pulse.

Cathode imaging shows a visual increase in image intensity. This is shown in Fig. 5, which is a set of images from a camera gated 269 ns into the pulse. The scintillator images, also shown in Fig. 5, show a visual increase in beam intensity and beam area.

Comparison to Simulated Data

Experimental current consistently reads higher than what is predicted at higher diode voltages. When the emission surface is reduced, decreasing the effective recess, the experimental current matches the simulated values. A similar process was performed by Delaunay et al. [6] and it was determined that the plasma was expanding, decreasing the effective recess. This is likely the cause of the difference in extracted current for our case. At higher measured voltages, the current matches closely with that extracted from a cathode with a reduced emission surface of 2 mm. Evidence of this can be seen in Table 1.

[1] These emittance and current values calculated through Trak change with respect to mesh size and shape.

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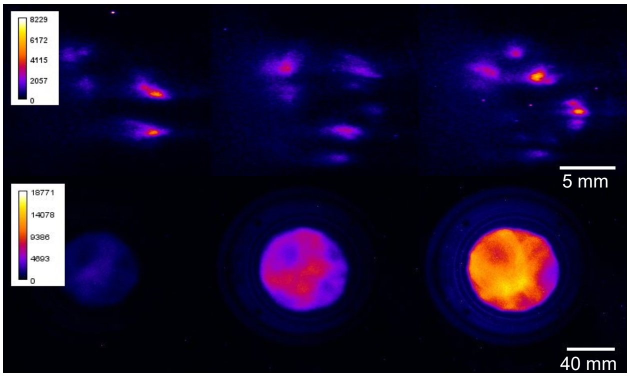

Figure 5: Images of the cathode (top) and scintillator (bottom) at differing diode voltages 269 ns into the pulse (left: shot 7086, middle: shot 7116, right: shot 7128).

Table 1: Comparison of Experimental Data to Simulated Data at Different Emission Locations

Diode Voltage [kV]	Extracted Current [A]	Simulated: Actual Recess [A]	Simulated: 2mm Offset [A]
185	84	60	92
221	117	77	119
258	154	96	149
285	194	111	172

EXPLORING NEW GEOMETRIES

Utilization of a Pierce geometry allows for a more uniform current density and beam distribution with a lower emittance. Using Trak, a cathode plug has been designed which implements an 80^0 Pierce angle, as seen in Fig. 6. The cathode plug is recessed 3mm as before, but the angle pushes the emission surface back another 0.92 mm. The emission surface diameter and AK gap are held identical to that of simulations described earlier, i.e., a 15mm cathode diameter and 22 mm AK gap.

For an operating voltage of 250 kV, the extracted current is 74.31 A and the emittance, measured 10 cm from the tip of the plug, is 61.06 pi-mm-mrad. When a flat cathode is recessed 3.92 mm, the produced current and emittance is 75.91 A and 81.87 pi-mm-mrad, respectively. Comparing to the data extracted with a flat cathode recessed 3 mm (identical to that in the CTS), the extracted current is higher at 91 A and the emittance comparable to that of the Pierce geometry at 68 pi-mm-mrad. The potential surfaces give a 'flatter' and more uniform distribution, but only slightly. Here, we keep in mind that the emittance has been measured at Z = 10 cm and the diode voltage set to 250 kV.

FUTURE WORK

As it stands, emittance measurements cannot be made on the CTS. However, a pepperpot mask has been designed, which will produce this measurement when coupled with the scintillator. This diagnostic will be employed within the coming months.

Moving forward, newer materials will be tested as a substitute for the velvet cathode. Promising results have been produced using CsI coated velvet [7] and graphite [8]. Additionally, the Pierce geometry will be fabricated and tested with the velvet material.

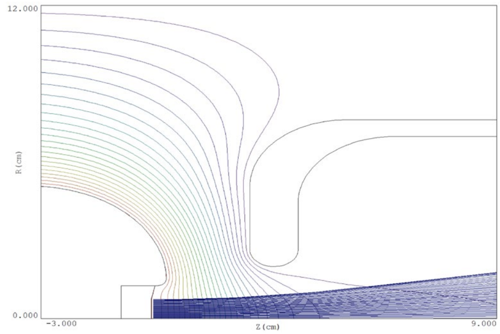

Figure 6: Design for a cathode with Pierce geometry.

CONCLUSION

Simulations of the diode show that as the cathode is recessed, the current decreases. In addition, the emittance initially decreases with recess, then increases slightly. Experimental data shows an increase in diode voltage, extracted current, measured pulse length, and emission area as the PFN charge is increased. At first glance, the experimental extracted current is higher than that predicted by Trak. However, once the axial location of emission is altered by 2 mm, there is an agreement. This suggests that the emission location may be altered throughout the pulse. The Pierce geometry creates a cathode with a similar extracted current to that of the flat cathode with the same recess. However, the current is less than that measured with the CTS design. The simulated 4rms emittance is lower than that of the other cathodes. Implementing this geometry may result in a higher brightness electron beam than what is currently extracted on the CTS.

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