ELECTROSTATIC MODELING OF THE JEFFERSON LABORATORY INVERTED CERAMIC GUN

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Abstract

Jefferson Laboratory (JLab) is currently developing a new 500kV DC electron gun for future use with the FEL. The design consists of two inverted ceramics which support a central cathode electrode. This layout allows for a load-lock system to be located behind the gun chamber. The electrostatic geometry of the gun has been designed to minimize surface electric field gradients and also to provide some transverse focusing to the electron beam during transit between the cathode and anode. This paper discusses the electrode design philosophy and presents the results of electrostatic simulations. The electric field information obtained through modeling was used with particle tracking codes to predict the effects on the electron beam.

INTRODUCTION

Experience of operating the JLab FEL DC photo gun suggests that when high voltage (HV) electrodes are properly prepared and conditioned, it is possible to operate at 350kV with an electric field of 8.7 MV/m on the surface without field emission. One of the goals of the new design is to keep the maximum electric field on the surface of the electrodes below 8.7 MV/m with a gun voltage of 500kV.

The inverted ceramic gun is designed to nominally deliver 135pC electron bunches at a maximum repetition rate of 75MHz. An overview of the electron gun design is given in [1] can be seen in figure 1.

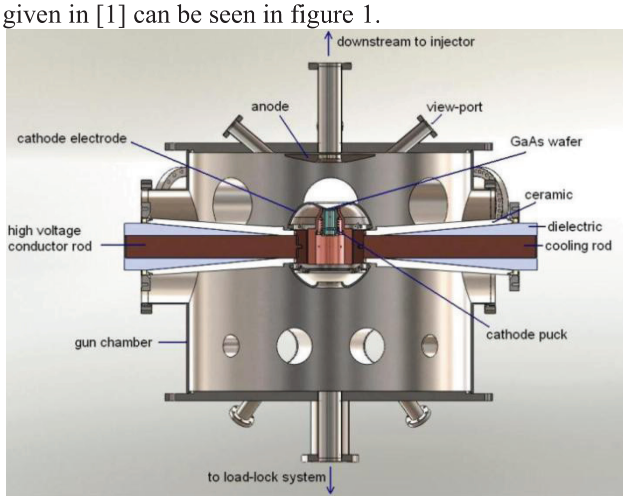

Figure 1: Cross-section overview of the inverted ceramic gun from above

The design consists of two conical ceramics, which support the cathode electrode in the center. The diameter of the cathode electrode is 24cm, chosen to limit the surface electric field to below 8.7MV/m in conjunction with the radius of the cylindrical gun chamber. The vacuum chamber is therefore 76.2cm in diameter.

ELECTRODE DESIGN

Three different criteria were used during the electrostatic design. First, the field gradient of the cathode electrode surface should be less than the limit mentioned above. Second, the electron beam emittance should be less than that required by the IR FEL operated at ~1micron wavelength with the electron beam energy of ~100MeV. Third, the gun geometry should provide electrostatic focusing to reduce the size of the beam going through the anode aperture and beam pipe downstream, and also to keep the beam centered on axis if operating the drive laser spot off-center on the cathode. This will also serve to prevent cathode damage by de-focusing back streamed ions.

Cathode Ball

To make the problem two dimensional for the first stage of modeling the gun geometry was assumed to be axially symmetric. The Poisson electrostatic solver [2] was used to calculate the electrostatic field distribution. PARMELA [3] was used to calculate the beam dynamics.

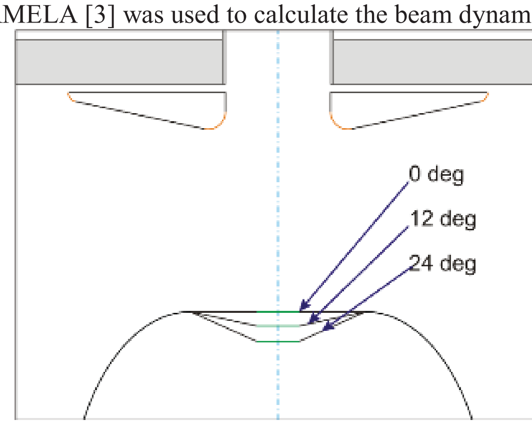

Figure 2: Focusing geometry options

Three options of the cathode electrode geometry with different degrees of focusing were considered. The options have angles of 0º, 12º and 24º between the cathode plane and the focusing part of the electrode as shown in Fig. 2. The transverse phase space distribution at 23cm from the cathode is shown in figure 3 for each option.

For the 24º option the beam size is smallest and is more centered on axis. Additionally, the emittance essentially did not change. If 500kV cannot be achieved, electron beam performance at 350kV is very similar.

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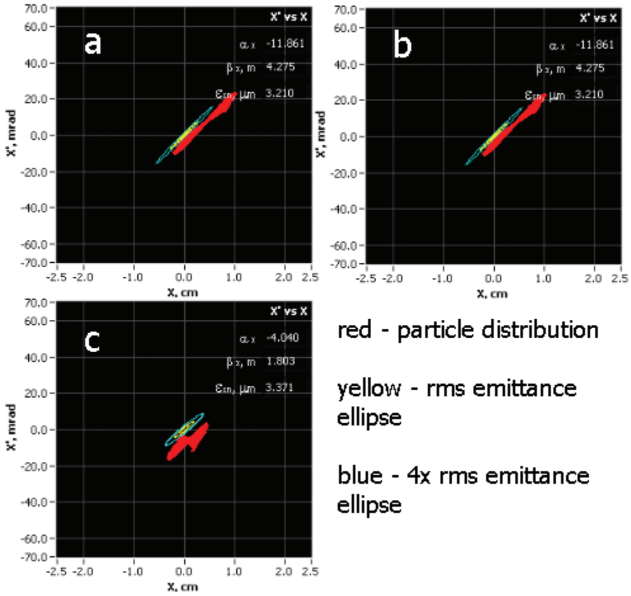

Figure 3: Transverse phase space a) 0º, b) 12º, c) 24º (0.4cm offset, 0.8cm diameter, 50ps FWHM emission from cathode, 500kV, 135pc)

Anode

Several options were also considered for the anode plate geometry. For this gun configuration there was no significant change in the beam quality for different anode shapes while moving it closer to the cathode naturally increases the field gradient on the cathode electrode. The new anode plate therefore, has the same diameter as the cathode ball and has a conical surface. The angle between the axis of the system and the cone surface is 78º. The purpose of the cone surface is to direct the wake-fields generated on the anode plate away from the cathode electrode.

ELECTROSTATIC MODELLING

To investigate the effects of the ceramics, chamber dimensions, high voltage conductive rod and dielectric on the fields between the cathode and anode, 3D software must be used as there is only one plane of symmetry in the complete design. The CST electrostatic solver software [4] was used in this instance to model the fields throughout the gun chamber and the implications they would have on electron beam quality.

Ceramic

As described in [1] the cathode ball is supported in the centre of the gun chamber by two conical ceramics. Internal to one ceramic is a conducting rod, connected to the high voltage power supply. Inside the second ceramic is a hollow rod, held at high voltage through contact with the cathode ball, used to supply cooling to the photocathode. The conducting rod must be placed inside each ceramic to ensure the electric field is symmetric about the electron axis. Figure 4 demonstrates the effect of removing the cooling rod. The slight asymmetry in the potential that arises from only one conductive rod leads to significant distortion of the electron beam at the gun exit, exaggerated by the low electron energy in this region.

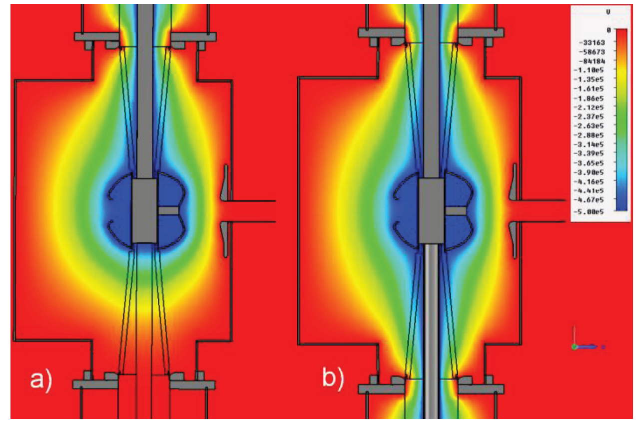

Figure 4: Top view of the potential, a) without b) with a second conducting rod.

The ceramic is fabricated with a bulk resistivity of $7.4\text{x}10^9$ Ωm. Small amounts of current should then bleed off to avoid charging and discharging of the ceramic. Other ceramic materials with lower resistivity are also being investigated as this will serve to grade the potential along the ceramic length uniformly, thus reducing the gradients in the ceramic and eliminating the need for a metallic cooling rod to maintain field symmetry. The effect of reduced resistivity (increased conductivity) is shown in figure 5.

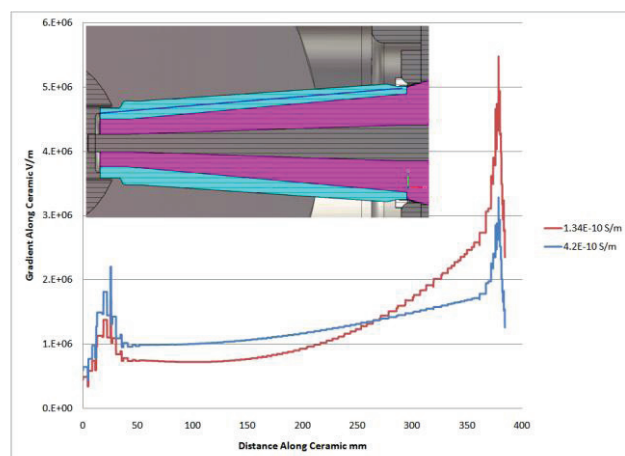

Figure 5: Gradient along the ceramic for different bulk conductivity materials. The ceramic is shown in blue, the dielectric in pink. The cathode electrode is on the left, and the ground-end flange on the right.

Dielectric

The dielectric material is required to reduce the possibility of electrical breakdown between the conductive rod and the ceramic. The model shows the highest gradient of ~19MV/m, is found at the conductive rod/ dielectric interface at the entrance into the gun chamber, shown in figure 6. This gradient is enough to breakdown the SF_6 environment used in power supply chamber.

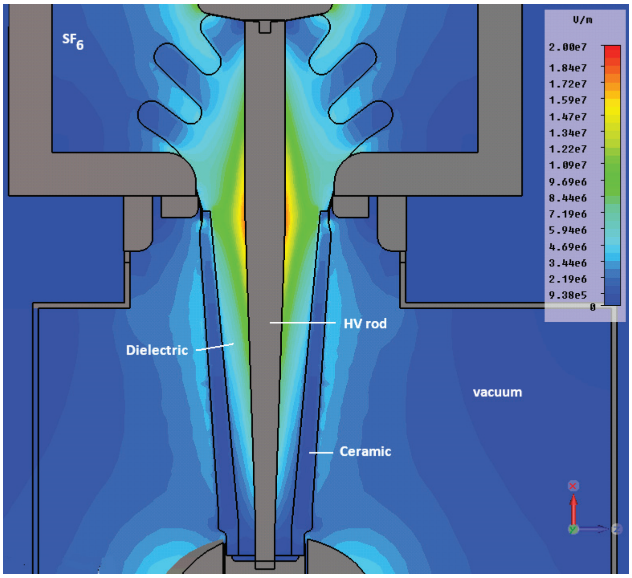

Figure 6: Gradient in the dielectric at 500kV

Cathode Electrode

The cathode electrode will be manufactured in 4 separate niobium parts that clamp together around the cathode holder assembly. Experiments show that the onset of field emission from niobium is at higher gradients than the stainless steel commonly used for electrodes. The edges of each niobium part will be machined with a small radius so that the joints will not enhance the gradient on the surface of the cathode ball, figure 7. Also shown is the maximum gradient of 8.5MV/m on the electrode front face. This is calculated at a voltage of 500kV. It should be noted that this is less than the gradient achieved on the present FEL DC gun at 350kV, so for this reason, field emission should not be a problem in this region.

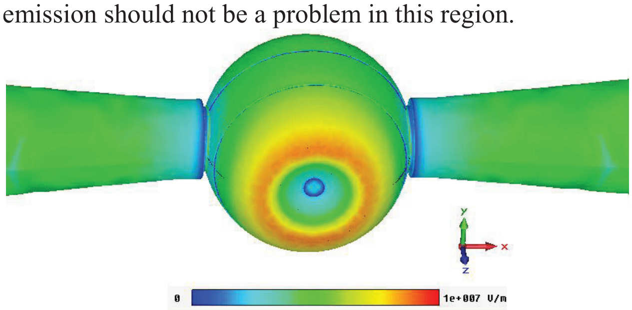

Figure 7: Surface gradients on the cathode electrode

Cathode/Anode Fields

The electrostatic model can be used to generate the fields on the nodes of a grid between the cathode and anode. The longitudinal field on the ideal electron axis is shown in figure 8. The gradient at the center of the cathode is 2.1MV/m. Figure 9 illustrates the slight variation in transverse fields in the X and Y planes off axis due to the ceramics being in one plane only.

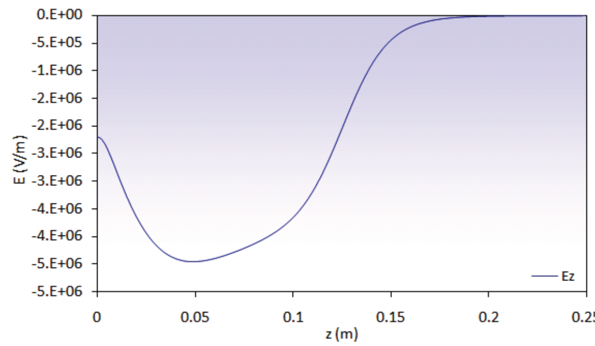

Figure 8: On axis field Ez as a function of distance from the cathode

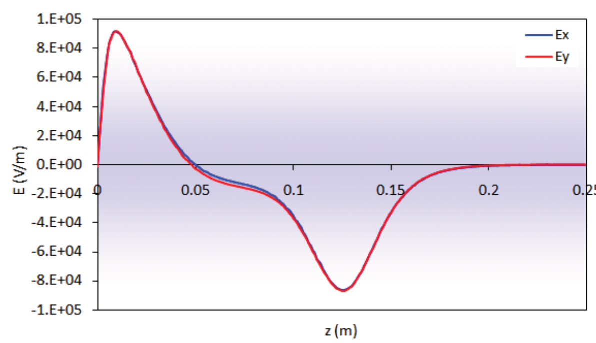

Figure 9: Transverse fields (Ex and Ey) at 1mm off axis as a function of distance from the cathode

OUTLOOK

Fabrication of this gun is underway. The gun chamber has been manufactured and the ceramics and dielectric pieces are currently being made in industry. Once completed in 2011, it will then be placed in the Gun Test Stand to undergo high voltage processing and electron beam measurements.

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