DESIGN OF A DC/RF PHOTOELECTRON GUN*

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Abstract

An integrated dc/rf photoelectron gun produces a low-emittance beam by first rapidly accelerating electrons at a high gradient during a short (~ 1 ns), high-voltage pulse, and then injecting the electrons into an rf cavity for subsequent acceleration. Simulations show that significant improvement of the emittance appears when a high field (~ 0.5 – 1 GV/m) is applied to the cathode surface. An adjustable dc gap (≤ 1 mm) which can be integrated with an rf cavity is designed for initial testing at the Injector Test Stand at Argonne National Laboratory using an existing 70-kV pulse generator. Plans for additional experiments of an integrated dc/rf gun with a 250-kV pulse generator are being made.

INTRODUCTION

The limitations on conventional electron rf photoinjectors are largely due to space charge induced emittance growth. This growth is particularly severe at low electron energies, i.e., near the cathode. To eject electrons from a photocathode source, a laser beam irradiates a photocathode embedded in an accelerating field. In an rf photoinjector, electrons released by the laser are accelerated by an rf field to relativistic velocities, thus reducing the emittance degradation during acceleration of a high intensity beam. The peak rf field in a photoinjector, however, is limited by the available rf power and by voltage breakdown. Recent work at Brookhaven National Lab (BNL) and elsewhere [1] suggests that using a short-pulse dc field that is much higher in amplitude than typical rf fields in a photoinjector can greatly suppress the space charge induced emittance.

In a dc/rf gun [2], a pulsed dc electric field quickly accelerates photoelectrons across a small gap between the photocathode and the backplane of an rf cavity. The electrons are then immediately injected into the rf cavity for further acceleration. Figure 1 shows a system schematic of the dc/rf gun, which consists of a high voltage (HV) pulse generator, an HV transmission line, a cathode/anode gap and rf cavities. The essential feature is the pulsed, high gradient field (~GV/m) that is created in the dc gap, since electrical breakdown occurs at larger fields for smaller pulse lengths. Recent advances in fast semiconductor switches have made possible short pulse, HV generator with high rep rate (> 10 kHz) [3], which can produce a large field in the dc gap. This would significantly improve the emittance while maintaining a high repetition rate, a high charge per electron bunch, and a small beam size.

In addition to the reduction of transverse emittance, another advantage of the proposed dc/rf photoelectron gun is the decrease of the work function of the photocathode due to the Schottky effect.

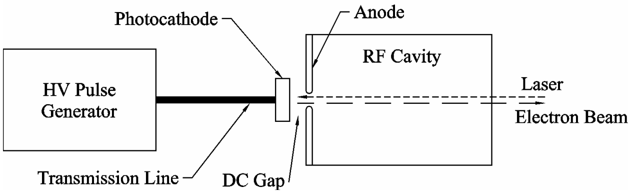

Figure 1: System schematic of the dc/rf gun.

DC GAP PERFORMANCE

Preliminary work was performed using the POISSON and PARMELA codes to simulate the performance of the dc gap first without the additional influence of the rf field. A simple geometry used in the simulations consisted of a flat cathode and anode with a 1 mm spacing and a circular aperture in the 1 mm thick anode plate that forms the backplane of the rf cavity. Figure 2 shows the normalized beam emittance through the gap with a 1 mm aperture as a function of the inverted dc voltage for several values of the bunch charge (0.1-1.0 nC). The initial bunch rms radius (.15-.35 mm) and bunch length (5-10 ps) were varied to obtain the minimum emittances. For the initial experiment, planned to be performed at the APS Injector Test Stand (ITS) at ANL a 70 kV pulser (on loan from LBNL), after voltage inversion, will accelerate a 0.1 nC bunch. The anticipated value of the emittance at the time of injection into the rf cavity is approximately 0.36 mm-mrad, not including thermal emittance.

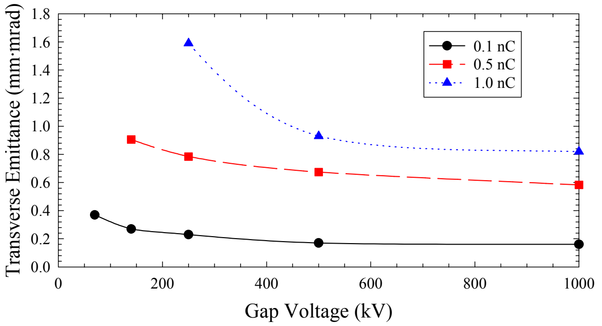

Figure 2: Emittance as a function of applied dc voltage for 0.1, 0.5, and 1.0 nC bunch charge.

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From Figure 2, it is evident that an increase in the magnitude of the (inverted) dc voltage at the cathode will result in a reduction of the emittance. Increasing the gap voltage difference more than 500 kV does not improve the emittance, although it may improve subsequent rf acceleration. Figure 3 shows the PARMELA results as a function of axial distance for 70 kV and 1 MV dc acceleration of a 0.1 nC bunch charge. Our simulation results show a lower normalized transverse emittance when compared with the work at Eindhoven University of Technology in the Netherlands [2] which used a very short laser pulse (50 fs) compared to the standard S-band laser pulse (5-10 ps). The longer pulse at the same charge significantly mitigated space charge effects.

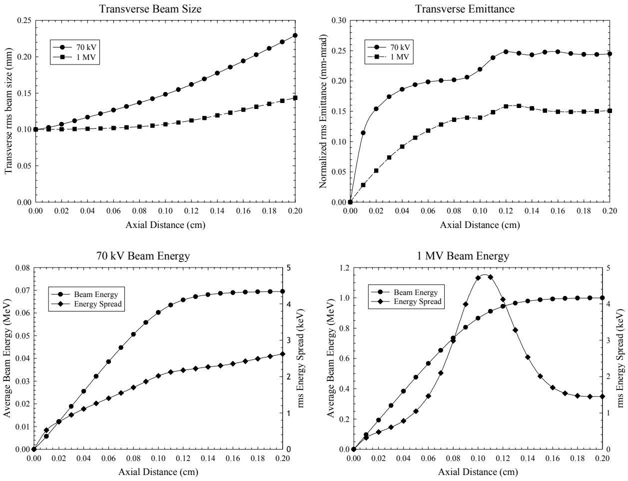

Figure 3: PARMELA results for the dc gap beam parameters with a gap voltage of -70 kV and -1 MV. Thermal emittance is not included in the calculation.

TIME DOMAIN SIMULATIONS OF DC GUN HEAD AND TRANSMISSION LINE

In preparation for initial testing with a 70 kV pulser, a dc head and transmission line were modeled using the 3D electromagnetic code CST Microwave Studio. The gun head consists of two pieces: a connector (Figure 4) and a terminated transmission line (Figure 6). The connector is the section that attaches to the pulser and transitions to the transmission line. The transmission line starts at the end of the tapered section of the connector, continues through a ceramic cone that forms the vacuum boundary, as well as providing mechanical support, and ends at the anode plate (backplane of the rf cavity) including the 1 mm gap.

Because of the space constraint at the ANL test facility, the transmission line was quite short so that the signal transit time is comparable to the pulse length. The two port device was designed with a characteristic waveguide impedance of 100 Ω, assuming the resistor termination is near the gun head. The impedance would of course be different if the resistor termination is placed inside the pulser instead. The end of the coaxial connector that attaches to the pulser is filled with teflon PTFE as a dielectric insulator. The other end of the connector transitions into an air filled coaxial transmission line that leads to a ceramic cone and the dc gap.

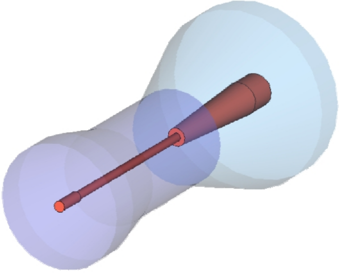

Figure 4: Model of the connector: the center conductor is connected to the pulser on the left, and slips into a precision hole on the large taper on the right.

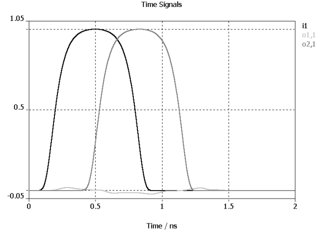

Figure 5: Transient simulation results of the connector: input (black), transmitted (gray), and reflected (light gray) signals of the 2-port device

The transmission line portion of the dc/rf gun has two parts separated by a ceramic cone. The section closer to the pulser is an air filled coaxial transmission line that matches the pulser connector and includes the resistor termination at the other end. The section on the other side of the ceramic cone is a vacuum filled transmission line encompassing and dc gap. Figures 6 and 7 show the model and the results of the simulation, respectively.

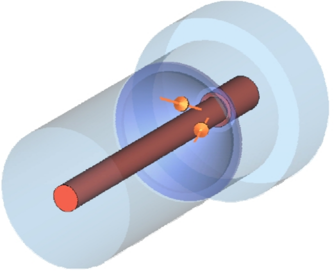

Figure 6: Model of the terminated transmission line and dc gap. The connector extends to the left of the figure.

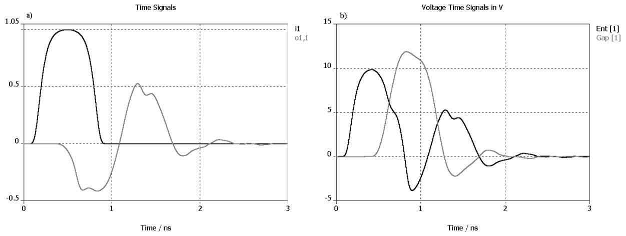

Figure 7: Transient simulation results of the transmission line/gap: a) input (black) and reflected (gray) time signals, b) inverted voltage at the dc gap (gray) and at the entrance of the transmission line (black) as a function of time.

The small, inverted reflection signal appears to come from the discontinuity presented by the ceramic cone. The large, upright reflection is expected from the capacitive nature of the transmission line termination at the dc gap, in addition to the indication of charging and discharging of a capacitor. The gap voltage (gray trace in Figure 7b) is about 15% higher than the applied voltage at the entrance of the transmission line because there is a mismatch with the combined impedances of the ceramic cone, terminating resistors and the gap, causing some reflection (gray trace in Figure 7a).

MECHANICAL DESIGN OF DC GUN HEAD

Figure 8 shows a preliminary design of the 70 keV dc gun head. The gun head was designed specifically for attachment to the BBC rf gun [4] at the APS/ITS (not shown, at left). The BBC gun backplane has a thin taper around the cathode hole, which should help reduce the beam transit time from the dc gun head to the rf cavity. The connector mounts to a stationary pulser which produces a –70 kV pulse of 1-2 ns (not shown, at right of Figure 8) using a teflon filled transmission line. The design will be modified with an oil filled transmission line later for a test with a 250 keV pulser.

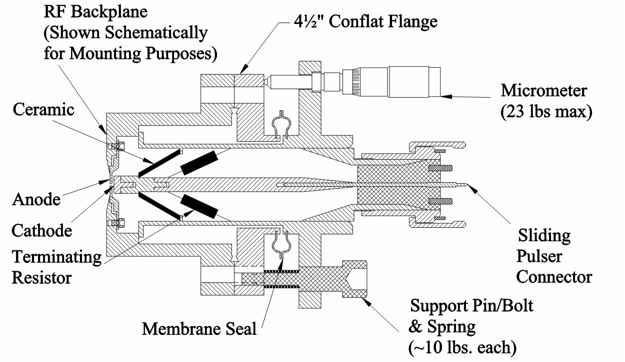

Figure 8: Schematic of the dc gun head for integration into the BBC gun at ANL/ITS.

The cathode/anode gap is adjustable using 3 precision micrometers. During the adjustment, the pulser/connector, the anode plate (rf backplane) and the vacuum flanges remain fixed. The thicker inner conductor on the gap side slides over the thinner inner conductor protruding from the connector; and the outer conductor moves along a sliding joint where the connector tapers from the teflon filled transmission line. A membrane seal allows axial motion of the outer conductor while maintaining the vacuum. Extension of the micrometers would result in an increase in the cathode/anode gap. Springs are added in the support pins to reduce the load on the micrometers due to the vacuum boundary.

HIGH ENERGY INJECTION

Several rf guns were simulated to see if the injection of high energy electrons would improve their performance. PARMELA simulations were compared for two different situations: a beam with a high initial kinetic energy as though it were from a dc gun (with negligible initial emittance and energy spread), and a beam injected from a photocathode in a normal rf gun. Figure 9 shows the simulation results for the AWA gun [5] with a 40 nC bunch charge and an initial injection energy of 1 MeV. Similar improvement (Figure 10) is seen for the BBC gun with a 0.8 nC charge and an injection energy of 1 MeV.

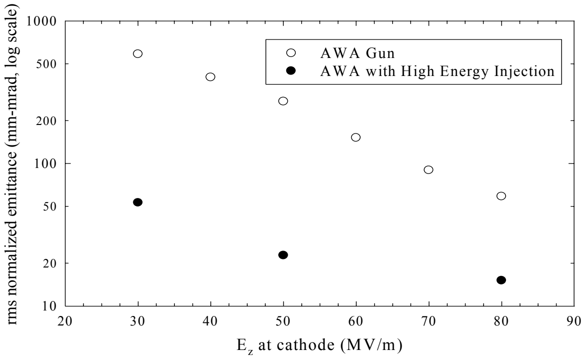

Figure 9: Transverse emittance calculated for the AWA gun with and without high energy injection.

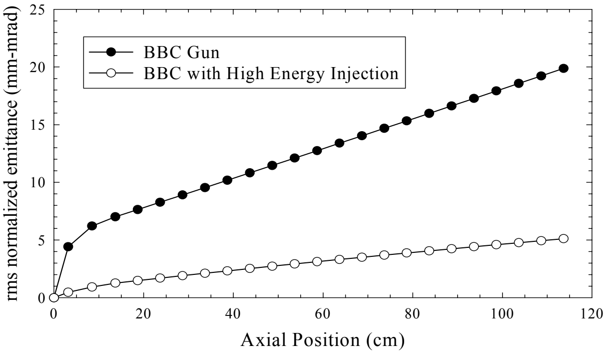

Figure 10: Emittance for the BBC gun running in π-mode with and without high energy injection.

CONCLUSIONS

A dc/rf gun head was designed and will be ready for testing with the BBC gun at ANL soon after the commissioning of the BBC gun. Simulations indicate that injecting high energy electrons into an rf cavity results in a significant decrease in the transverse emittance.

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