1997 Particle Accelerator Conference, 5/12/97-5/16/97,
Vancouver/BC Canada*
CONF-970503--80
BNL-64467

Beam Dynamics Enhancement due to Accelerating Field Symmetrization in the BNL/SLAC/UCLA 1.6 cell S-Band Photocathode RF Gun*

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Abstract

A 1.6 cell photocathode S-Band gun developed by the BNL/SLAC/UCLA collaboration is now in operation at the Brookhaven Accelerator Test Facility (ATF). One of the main features of this RF gun is the symmetrization of the RF coupling iris with a identical vacuum pumping port located in the full cell. The effects of the asymmetry caused by the RF coupling iris were experimentally investigated by positioning a metallic plunger at the back wall of the vacuum port iris. The higher order modes produced were studied using electron beamlets with 8-fold symmetry. The 8-fold beamlets were produced by masking the laser beam. These experimental results indicate that the integrated electrical center and the geometrical center of the gun are within 175 μm. Which is within the laser alignment tolerance of 250 μm.

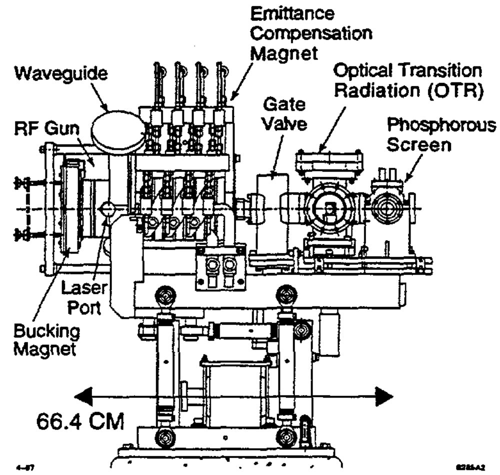

Figure 1: The BNL/UCLA/UCLA 1.6 cell S-band photoinjector

1 INTRODUCTION

The BNL/SLAC/UCLA S-band emittance compensated [1] photoinjector has been installed at the Brookhaven Accelerator Test Facility(ATF) as the electron source for beam dynamics studies, laser acceleration and free electron laser experiments. The 1.6 cell rf gun is powered by a single XK-5 klystron, and is equipped with a single emittance compensation solenoidal magnet. There is a short drift space between the photoinjector and the input to the first of two SLAC three meter travelling wave accelerating sections. This low energy drift space contains a copper mirror that can be used in either transition radiation studies or laser alignment. There is also a beam profile monitor/Faraday plate located 66.4 cm from the cathode plane. The photoinjector beam line layout is presented in figure 1.

The drive laser is a Nd:YAG master oscillator/power amplifier system. A diode pumper oscillator mode locked at 81.6 MHz produces 21 psec FWHM pulses at 100 mW of average power. Gated pulses seed two flash lamp pumped multi-pass amplifiers and are subsequently frequency quadrupled. This nonlinear process leads to a factor of two reduction in the laser pulse length. The 266 nm beam is transported to the RF gun area via a 20 meter long evacuated pipe. A spherical lens and a pair of Littrow prisms are used to compensate for the anamorphic magnification introduced by the 72° incidence on the cathode. The time slew across the cathode caused by this oblique incidence is also corrected by using a diffraction gradient.

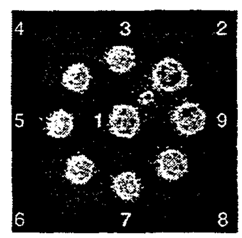

Figure 2: Beamlet profile on cathode, the distance from beamlet 1 to beamlets 2-9 is 1mm

To probe the electromagnetic fields of the 1.6 cell gun an 8-fold symmetric aperture [2] [3] was introduced into the laser beam line. This 8-fold aperture produces a laser image on the cathode seen in figure 2 with the radius of 1 mm from the center beamlet to the outer ring of beamlets. This produces an electron beam with 8-fold symmetry. This aperture was rotated to align the symmetry breaking beamlet to be collinear with the waveguide feed into the gun.

2 EXPERIMENTAL SETUP

The rf guns half cell is fully symmetrized by two laser ports which are located rotated 45° from the tuner/waveguide coordinate system in the fully cell. These two laser ports al-

* Work supported by the Department of Energy, contracts DE-AC03-76SF00515 and DE-AC02-76CH00016

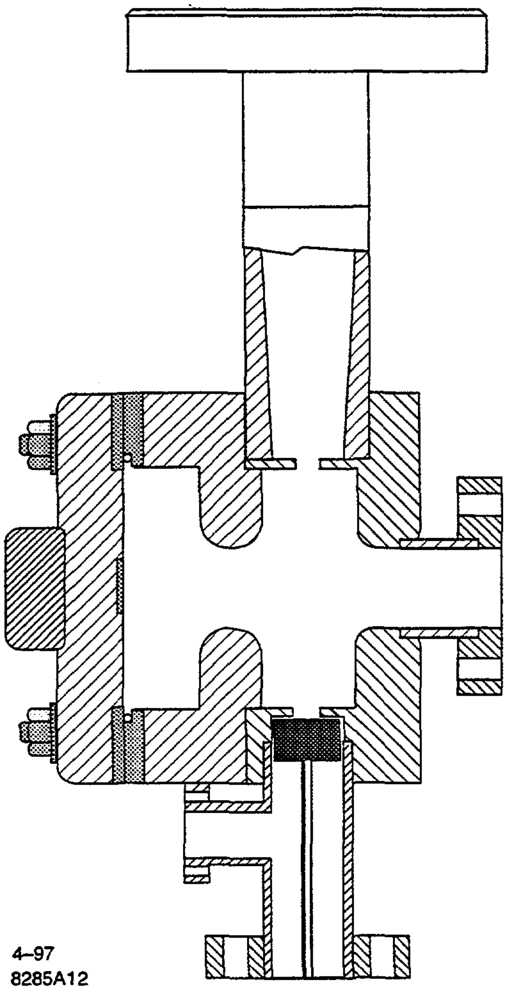

Figure 3: rf gun in the unsymmetrized case

low for uv light to illuminate the cathode at a grazing incidence angle of 72° from beam line and also prevents multiple scattering of the uv in the half cell of the gun. Since the half cell is full symmetrized the integrated asymmetry of the rf gun is only due the full cell.

In these experiments an stepping motor controlled UHV linear motion feed-thru drawing a shorting plunger with a total travel of 10 cm was used to symmetrize or unsymmetrize the full cell of the rf gun. The shaft of the linear motion feed-thru was connected to a OFHC copper shorting plug that had no direct rf current path between it and the vacuum pipe wall.

In the symmetrized case, the shorting plunger is 10 cm from the vacuum port iris and the rf coupled into the vacuum port decays exponential. There is a rf power monitoring loop located in the vacuum pipe which is -70 db down from the input power.

The unsymmetrized case is shown in figure 3 with the shorting plunger at the maximum travel of the linear motion feed-thru. This positions the plunger to within 1.25 mm from the back wall of the full cell to vacuum port coupling slot which is 2.25 mm thick. Therefore we were not able to fully unsymmetrize the full cell the rf gun. The vac-

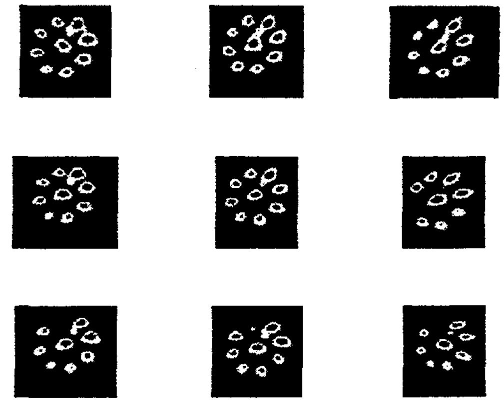

Figure 4: Beamlets profile with rf gun symmetrized

uum coupling slot is never eliminated and allows for some degree of symmetrization, even in the symmetrized mode of operation.

Another problem, in the unsymmetrized mode of operation, is that the vacuum tube and shorting plunger form a TEM coaxial transmission line and power is coupled from the full cell into the vacuum tube. In this case, the rf power monitoring loop is -20 db down from the input power. Combining the TEM coaxial transmission line problem along with our inability to fully unsymmetrize the full cell, a direct comparison of low power rf tests [4] and high power test is not possible.

3 HIGH POWER BEAM STUDIES

Phase variations in the rf gun, due to rf breakdown in the TEM coaxial conductor, prevented measurement of emittance growth due to gun asymmetrization from being conducted.

In the either mode of operation, the 8-fold beamlets were point to point focused, using the single emittance compensation magnet [5], to a beam-profile monitor screen located 66.4 cm from the cathode plane. The center beamlet profile in figures 4 and 5 represent the beamlet profiles in the symmetric and asymmetric mode of operation respectively, with the central beamlet on the geometric center of the rf gun. Mechanical alignment and dark current studies indicate that the geometrical and integrated electrical centers of the rf gun are with in 50μm of each other in the symmetrized mode. Steering the laser beam ± 1 mm on the x and y axis we are able to probe the electromagnetic field in the 1.6 cell rf gun out to a radius of approximately 2.4 mm and produce the eight additional images in both figures 4 and 5. It should be noted that the betatron rotation of the solenoidal magnet has been removed numerical from these images so that a direct comparison of the individual beamlet position and distortion can be directly compared to the full cells cavity penetrations.

In the analysis of the center 8-fold beamlets in figures 4 and 5 for the symmetrized and unsymmetrized mode of operation we have seem no centroid deflection for the outer

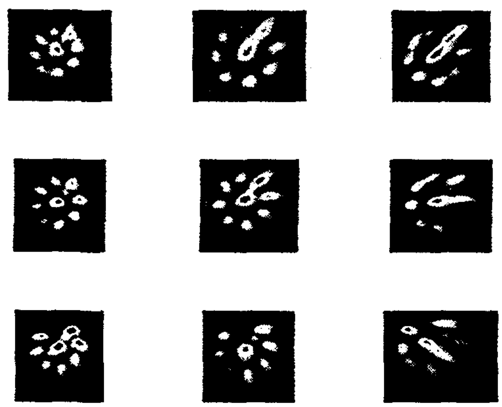

Figure 5: Beamlets profile with the rf gun unsymmetrized

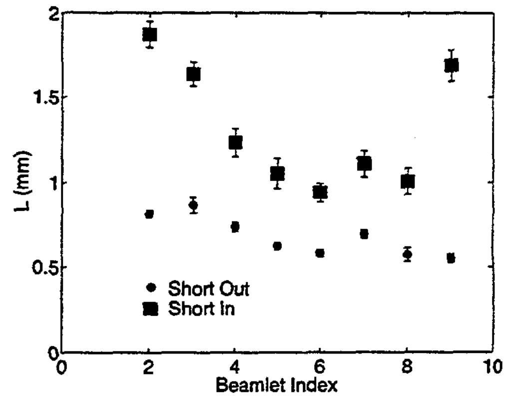

Figure 7: Individual beamlet radial extent

ring of beamlets with respect to the on axis beamlet, as is expected since the TM_{110} magnetic field is uniform in the beam region of the cavity. This effect is seem in figure 6. The difference in total deflection between the different modes of operation is due to the peak rf field that the rf gun could hold off was lower in the unsymmetrized cases, since the vacuum/plunger TEM coaxial conductor would breakdown at the higher rf fields used in the symmetrized mode of operation. The normalized deflection in both modes are approximately the same.

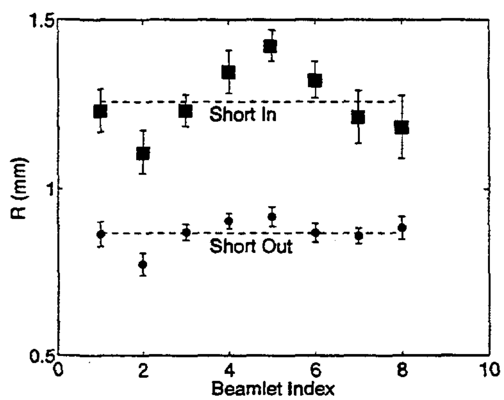

Figure 6: Beamlet centroid position from center beamlet

The effect of the symmetrized versus unsymmetrized mode of operation can be seem in figure 7. This figure represents the individual beamlets Full Width Tenth Maximum(FWTM) profiles. The data that represents the unsymmetrized mode of operation has a dominate dipole mode contribution as would be expected. In the symmetrized case the dipole contribution is minimized with the dominate mode being the quadrupole contribution, as would be expected from theory. Analyses is ongoing to fully understand this effect.

Multi-pole field effects were also studied by decreasing the laser spot size to 400 μm and setting the laser injection phase to the Schottky peak. This injection phase causes an effective electron bunch-lengthening and a noticeable energy-spread tail was observed. By adjusting the laser spot position we were able to eliminate this energy spread tail. This alignment minimizes the integrated higher-order-mode contribution to the beam distortion. Analysis indicates that the symmetrized BNL/SLAC/UCLA 1.6 cell photocathode rf gun's electrical and geometric center are within 170 μm of each other, which is within the laser spot alignment error. Compared to similar experimental results of the 1.5 cell BNL gun [6] whose electrical and geometric centers differ by 1.0 mm, the 1.6 cell gun has fulfilled the symmetrization criteria.

4 CONCLUSION

We have presented experimental data that indicates the dipole contributions has been significant reduced by symmetrizing the BNL/SLAC/UCLA 1.6 cell rf gun. Centroid deflection data is consistent with a uniform, magnetic field that is present with a TM_{110} contribution to the π accelerating mode. Beamlet energy spread profiles indicate the presence of a dominant dipole mode when in the unsymmetrized mode of operation and in the symmetrized mode the dominant mode is the quadrupole mode.

5 ACKNOWLEDGMENT

The authors would like to thank the technical staff at BNL, SLAC and at UCLA for all their dedicated work on this project.

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