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Experimental Results from a DC Photocathode Electron Gun for an IR FEL*

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Abstract

A 350 keV DC photocathode gun capable of delivering the high-brightness CW electron beam necessary for Jefferson Lab's infrared free-electron laser[1] is described. The gun is to be used with a superconducting radiofrequency linac operating at 1.497 GHz and is mode-locked to the 40th subharmonic of the fundamental using a Nd:YLF drive laser. The gun provides 20-25 ps bunches at up to 135 pC/bunch. Experimental measurements of transverse and longitudinal beam properties are presented. Transverse emittance is measured using a slit-wire scanner emittance meter, and energy spread is measured using the slit and a spectrometer magnet. Longitudinal emittance is measured using a combination of sampling aperture, kicker cavity, slit and spectrometer. Measurements for bunch charges of 135 pC are described and compared with simulations.

1 Introduction

The Jefferson Lab IR FEL injector consists of a 350 kV DC photocathode gun[2], a buncher cavity, and two superconducting cavities that accelerate the beam to 10 MeV. The length of the 350 keV beamline that was found to minimize emittance is ≈2.5 meters, allowing little space for diagnostics. Therefore, an injector test stand was built to verify operability of the gun and to carefully measure the properties of the 350 keV beam. The results of the test stand experiments are presented here. Measurements include beam size, transverse emittance, and longitudinal emittance. These quantities are compared with simulations using the Jefferson Lab version of PARMELA[3,4].

2 Layout of the Injector Test Stand

A schematic of the 350 keV gun test stand is shown in Figure 1. A frequency doubled Nd:YLF laser serves as the photocathode driver. The laser light enters the beamline through a window in the light box where it is reflected onto the GaAs cathode surface. The light is reflected off the cathode, strikes another mirror on the opposite side of the light box, exits the vacuum system, and is collected onto a photodiode. For these experiments, the laser spot distribution on the cathode had an rms radius of 3.0 mm and was truncated at R = 2.75 mm. Pulse structure is controlled by two Conoptics electro-optic modulators driven by an in-house pulser.

3 Transverse Emittance Measurements

Measurements of transverse emittance are performed by focusing the beam to a waist slightly upstream of the slit and then using the slit/wire sampling technique. Detailed measurements and descriptions at 250 keV have been performed and are presented elsewhere[2]. Only the results at 350 keV will be presented here. Shown in Table 1 are the measured values for normalized rms transverse emittance for 1, 38, 60, 135, and 171 pC bunches. Values generated by 3000 particle PARMELA runs are also shown and are in good agreement with the measurements. Though the laser spot size was chosen to avoid beam

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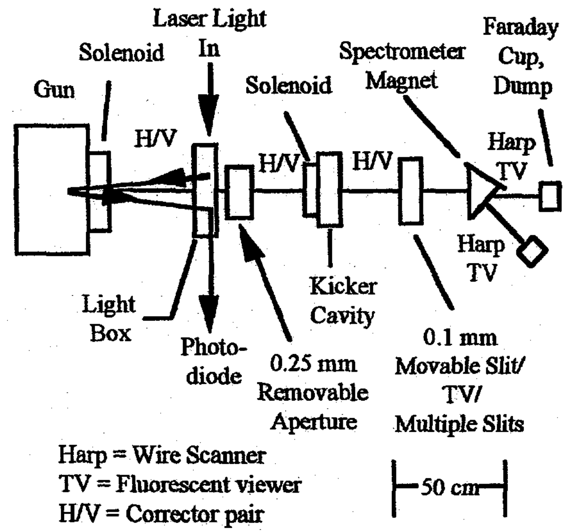

Figure 1. Schematic of the injector test stand.

scraping, the low values of measured emittance for 135 and 171 pC indicate that it is still present at these charges.

Table 1: Normalized rms transverse emittance ε_x for various values of charge per bunch Q.

Q [pC]	ε_x [mm-mrad], measured	ε_x [mm-mrad], PARMELA
1	0.85+/-0.2	0.81
38	1.8+/-0.2	1.95
60	2.4+/-0.3	2.2
135	3.5+/-0.4	3.8
171	3.8+/- 0.4	4.5

4 Longitudinal Emittance Measurements

Measurements of longitudinal emittance are performed using the 0.25 mm aperture, the second solenoid lens, the kicker cavity, the slit, and the spectrometer. Since space charge is causing the beam to expand rapidly in both the longitudinal and transverse dimensions, the aperture is used to create a sampled beamlet for which space charge effects are negligible. The longitudinal properties of the sampled beamlet can then be measured. By using steering

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magnets upstream of the aperture, longitudinal properties can be measured as a function of radial position.

A standard method for measuring longitudinal emittance [5] is to use a cavity to impart a time-dependent kick to the beam. In this case, the magnetic field of a 1497 MHz TM210 mode rectangular cavity produces the kick which causes the front of the bunch to get deflected in one direction and the tail in the other. The portion of the bunch that passes through the cavity when the oscillating field is zero receives no net deflection. By placing the slit at the location where electrons that are not deflected are transmitted through, the energy and energy spread of a section of the bunch can be measured. Adjusting the phase of the RF allows the energy and energy spread to be measured as a function of position in the bunch. From this data, the longitudinal emittance can be generated.

Plots of the longitudinal phase space for the beam sampled 0.8 mm and 6.0 mm from the beam axis are shown in Figures 2 and 3 respectively. Error bars are +/- 0.5 keV in energy and +/-0.5° in phase. The curved shape of the phase space in Figure 2 is indicative of distortions caused by nonlinear space charge effects. This effect does not occur near the edge of the beam where space charge is less. The PARMELA data is calculated using particles with radial position less than 0.5 mm of the given axial offset. This is twice the radius of the aperture and was chosen to allow sufficient statistical sampling of the 5000 total particles simulated. In spite of the qualitative agreement, there are several points of discrepancy.

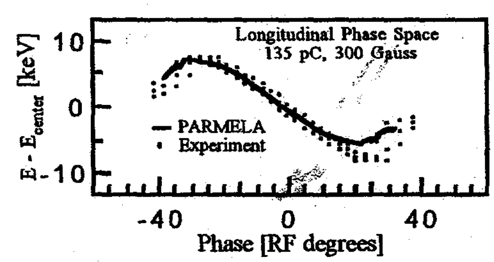

Figure 2. Longitudinal phase space of beamlet sampled 0.8 mm off-axis.

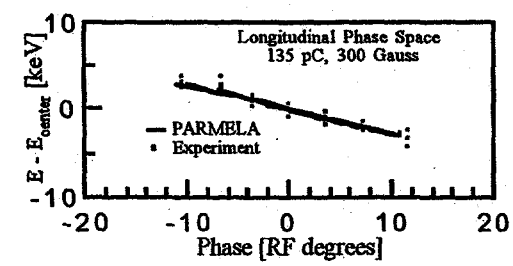

Figure 3. Longitudinal phase space of beamlet sampled 6.0 mm off-axis.

Errors arising from energy spread induced by the cavity and misalignments give rise to errors of <4 keV-degrees. However, finite beam size at the slit allows ≈5° of bunch to pass through causing the measured energy spread to be primarily determined by the tilt of the phase space instead of the actual energy spread of the slice.

Discrepancy is also evident in energy spread and beam size at the aperture. The measured rms beam size of 3.5 mm is significantly larger than the 2.5 mm PARMELA value. Figure 4, a plot of the full energy spread of the sampled beamlets and the simulated energy spread of the central beamlet, also shows a similar discrepancy. Even so, the longitudinal phase space plots indicate that the longitudinal emittance is not dramatically larger. PARMELA predicts that if the charge per bunch is doubled, the longitudinal emittance will increase from 12 to 15 keV-degrees. These numbers could indicate that the longitudinal emittance is growing more rapidly than expected. At present, these discrepancies are not understood and remain under investigation. Calculation of the rms longitudinal emittance from the data gives an artificially high value of 44 keV-degrees. However, this is primarily due to finite beam size error at the slit, creating a minimum measureable energy spread of ≈1 keV.

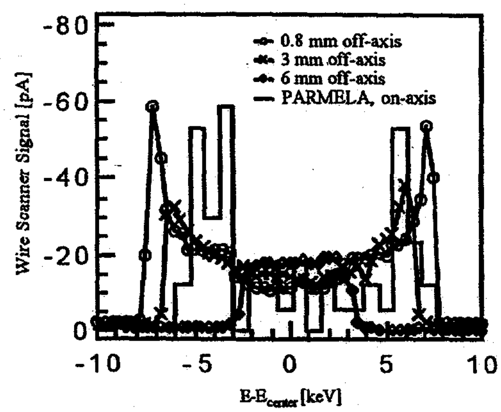

Figure 4. Plot of energy spread of beamlets sampled at 0.8, 3.0, and 6.0 mm off-axis. The profile generated by PARMELA simulation is derived from particles within 0.5 mm of the beam axis.

5 Conclusion

Detailed measurements of the transverse and longitudinal phase spaces indicate that the 350 kV DC photocathode gun should meet the beam requirements of the Jefferson Lab IR FEL. Discrepancies do exist in energy spread and transverse beam size measurements. These are being investigated further.

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