A NEW HIGH INTENSITY ELECTRON BEAM FOR WAKEFIELD ACCELERATION STUDIES*

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Abstract

A new RF photocathode electron gun and beamline have been built for the study of electron beam driven wakefield acceleration. The one and a half cell L-band gun operates with an electric field on the cathode surface of 80 MV/m, and generates electron bunches with tens of nanocoulombs of charge and rms bunch lengths of a few picoseconds. The beam diagnostics include a Cherenkov radiator and streak-camera for bunch length measurements, YAG screens for beam profile, integrating charge transformers (ICTs) for bunch charge, an energy spectrometer, and a pepper-pot plate for measurement of the transverse emittance. Measurements of the beam properties at various bunch charges are presented.

INTRODUCTION

The Argonne Wakefield Accelerator (AWA) has been successfully used for conducting wakefield experiments in dielectric loaded structures [1] and plasmas [2]. Although the initial wakefield experiments were successful, higher drive beam quality would substantially improve the wakefield accelerating gradients. For this reason we have built a new L-band photocathode RF gun [3]. This gun will generate high charge bunch trains which will be used in high gradient wakefield acceleration experiments and other high intensity electron beam applications.

FACILITY UPGRADE

The new AWA photocathode RF gun produces high charge electron bunches with shorter bunch length and lower emittance, in comparison with the previous AWA drive gun [4]. The new AWA laser system also presents superior performance in terms of beam profile, energy per pulse and stability.

New Electron Gun and Beamline

The new one and a half cell RF gun operates with a focusing solenoid and a bucking solenoid to cancel the magnetic field on the plane of the cathode. These two solenoids are exactly next to each other, with the photocathode plane as their plane of symmetry. A third solenoid is located at the exit of the gun. There is a vacuum pumping port in the full cell, located diametrically opposite to the RF coupler, both being at the equator line of the full cell. The initial photocathode consisted of a small disc of copper inserted through an opening on the back wall of the half cell. Recently, the photocathode material was replaced by a magnesium disc, which has a higher quantum efficiency. The cathode holder can also function as a tuning plunger, allowing us, in conjunction with the gun temperature, to adjust the parameters of the two cells, in order to achieve the right resonance frequency for the π mode and field balance in the cavity.

The measured value of the unloaded quality factor (Q_0) of the gun is 20300. The gun cavity is somewhat overcoupled ($S_{11} = -10$ dB), but the installation of a tuning post in the waveguide will improve the coupling. The new gun has been conditioned up to 13 MW of power, with a corresponding accelerating gradient on the cathode surface of 80 MV/m.

The beamline (Fig. 1) has an ICT for measurement of bunch charge at the exit of the gun, and another one downstream of the future wakefield structures to diagnose possible beam scraping. The beamline includes several insertable YAG screens for observation of the beam profile, a pepper-pot plate for measurement of the transverse emittance, and a quartz plate as a Cherenkov radiator for bunch length measurement in conjunction with a streak camera. A quadrupole triplet and an energy spectrometer are also installed in the beamline.

New Laser System

The new laser system consists of a Spectra Physics Tsunami oscillator followed by a Spitfire regenerative amplifier and two Ti:Sapphire amplifiers (TSA 50). It produces 1.5 mJ pulses at 248 nm, with a pulse length of 6 to 8 ps FWHM and a repetition rate of up to 10 pps. A final KrF Excimer amplifier is optionally used to increase the energy per pulse to 14 mJ.

BEAM MEASUREMENTS

Measurements of beam parameters are presented in this section. Some of the parameters are plotted as a function of the accelerating gradient on the cathode. This number was calculated from the value of the input RF power into the gun, using the measured value of the Q_0 of the cavity. In the near future a field probe will be installed in the gun cavity allowing for a more direct measurement of the field intensity.

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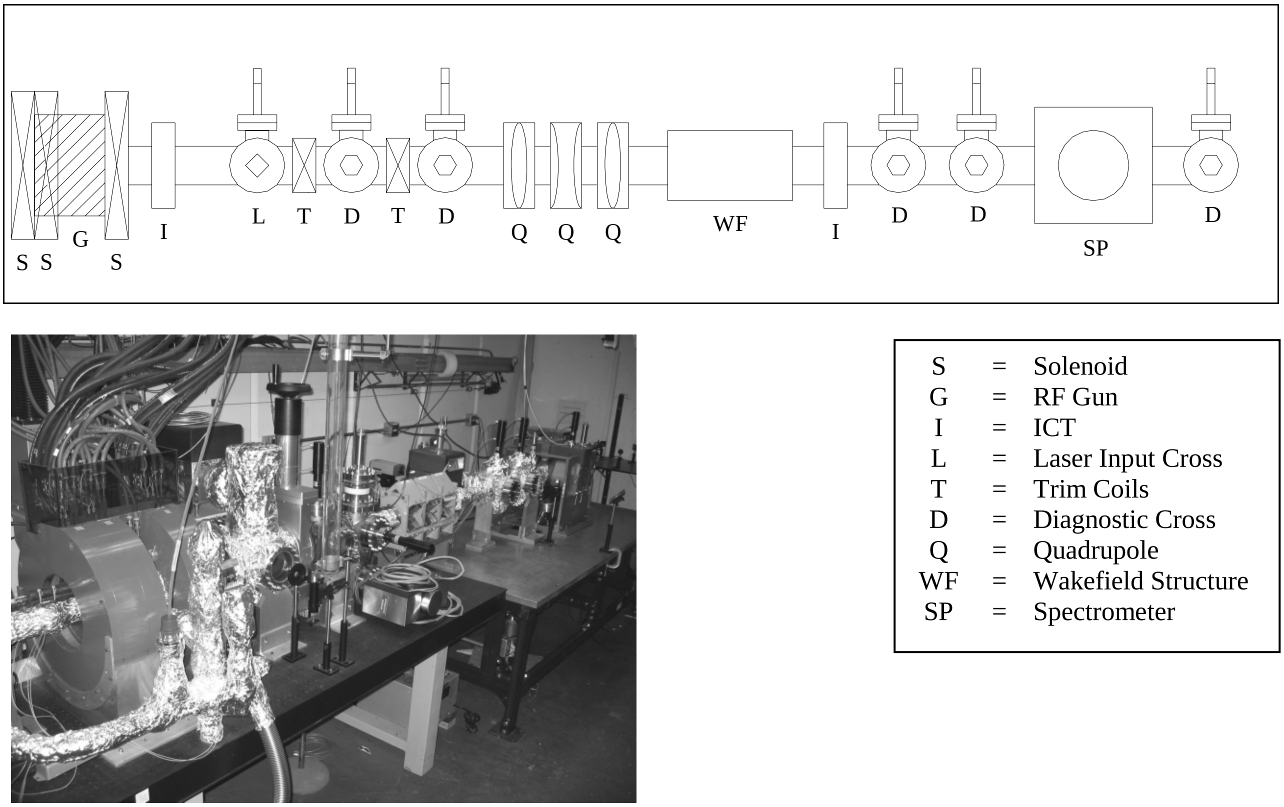


S = Solenoid
G = RF Gun
I = ICT
L = Laser Input Cross
T = Trim Coils
D = Diagnostic Cross
Q = Quadrupole
WF = Wakefield Structure
SP = Spectrometer

Figure 1: Schematic and picture of the new AWA beamline.

Dark Current

A Faraday-cup consisting of a ceramic DC break and an aluminum block was installed in the beam line for the measurement of dark current. An RC circuit with a time constant of 5 seconds connected to the Faraday-cup allowed an ammeter to measure the average dark current when the machine was operating at a rate of five pulses per second. Figure 2 shows a plot of the charge collected by the Faraday-cup per RF pulse as a function of the accelerating gradient on the cathode surface. We observe the expected rapid increase of dark current as the accelerating gradient in the gun is increased.

Bunch Charge

Using an ICT (Bergoz ICT-178-070-20:1), we have measured the bunch charge as a function of the laser pulse energy (Fig. 3a) and also as a function of the injection phase at the gun (Fig. 3b). The quantum efficiency of the magnesium cathode (presently about 1×10^{-4}) will improve when we implement the procedure for the laser cleaning of the cathode surface [5]. At the highest laser beam energies there is clear indication of space charge effects on the cathode, preventing the extracted charge from reaching much beyond 100 nC (Fig. 3a).

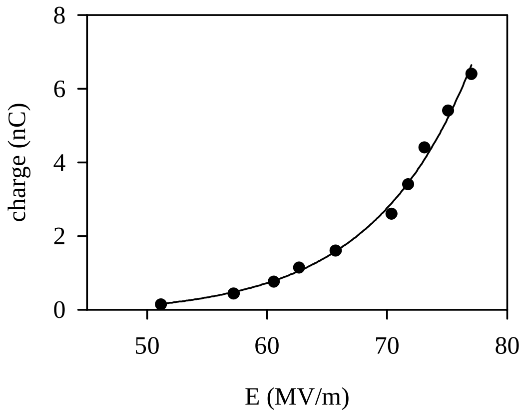
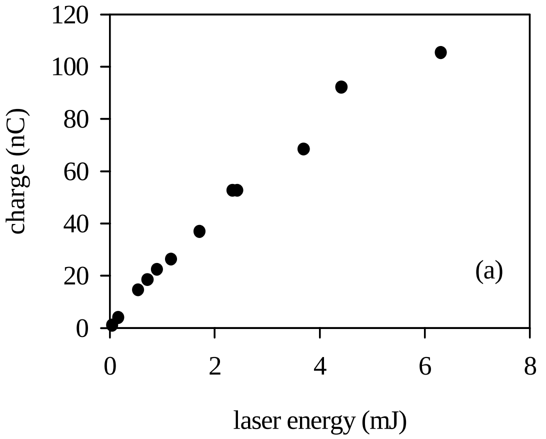


Figure 2: Dark current measurement. Average charge collected by the Faraday-cup during one RF pulse (about 6 μs long), as a function of the accelerating gradient on the cathode surface.

Beam Energy

The spectrometer at the end of the beamline was used to measure the energy of the electron beam. Figure 4 shows a plot of the beam energy as a function of the accelerating gradient on the cathode surface. This is in good agreement with numerical simulations (PARMELA) [6].



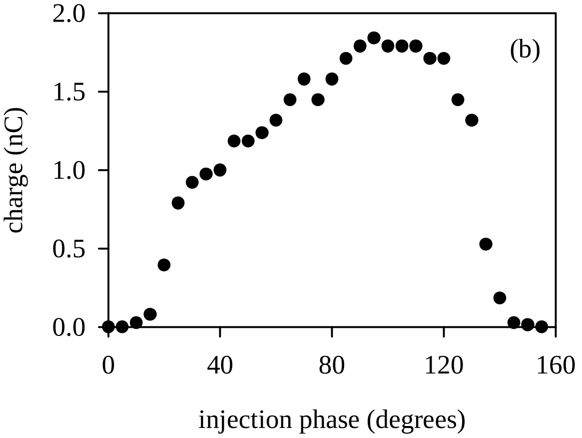


Figure 3: Measured bunch charge: (a) as a function of the laser pulse energy; (b) as a function of the injection phase.

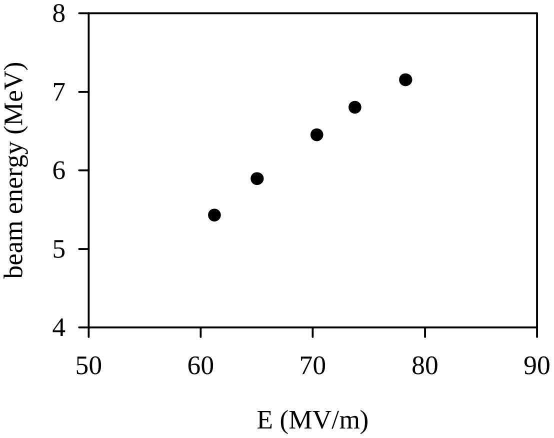


Figure 4: Electron Beam energy as a function of the accelerating gradient on the cathode surface.

Bunch Length

A 1.5 mm thick quartz plate was used as a Cherenkov radiator for bunch length measurements with a Hamamatsu C1587 streak camera. Initial measurements showed bunch lengths spanning from about 13 to 17 ps FWHM, for bunch charges up to 70 nC.

Transverse Emittance

A tungsten pepper-pot plate was used for transverse emittance measurements. The plate was 0.5 mm thick with 0.2 mm diameter holes spaced by 5.6 mm in a cross pattern. The profiles of the resulting beamlets are analyzed on a YAG screen. Preliminary data indicate a normalized emittance of 40 mm-mrad for 20 nC bunches.

IMMEDIATE NEXT STEPS

The splitting of the laser pulses into pulse trains, and the subsequent generation of electron bunch trains will be implemented right away.

A dielectric loaded wakefield structure has been built and will be installed in the new beamline very shortly. It will allow us to test the high power handling capability of the dielectric material.

CONCLUSION

The initial measurements of the beam parameters indicate good agreement with the design values, and confirm the tremendous improvement that the new AWA drive beam represents in comparison with the old drive beam. Some of the beam diagnostics will be further refined, allowing for more precise beam characterization and optimization of the operating parameters. The present magnesium photocathode will soon be replaced by a high quantum efficiency cesium telluride cathode, enabling the generation of long high charge bunch trains (16 or more bunches of 40 nC). A one meter long linac structure will be added to the beamline to increase the beam energy to about 18 MeV, lowering the physical emittance of the beam and facilitating studies of higher gradient wakefield structures.

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