Photocathode Driven Linac at UCLA for FEL* and Plasma Wakefield Acceleration Experiments

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Abstract

The UCLA compact 20-MeV/c electron linear accelerator is designed to produce a single electron bunch with a peak current of 200 A, an rms energy spread of 0.2% or less, and a short 1.2 picosecond rms pulse duration. The linac is also designed to minimize emittance growth down the beamline so as to obtain emittances of the order of 8πmm-mrad in the experimental region. The linac will feed two beamlines, the first will run straight into the undulator for FEL experiments while the second will be used for diagnostics, longitudinal bunch compression, and other electron beam experiments. Here we describe the considerations put into the design of the accelerating structures and the transport to the experimental areas.

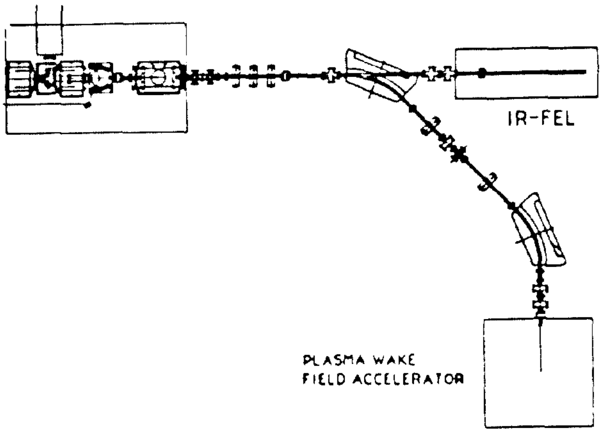

Figure 1: Beamline Layout

Introduction

In order to obtain a high-brightness electron beam we have employed an R.F. photoinjector[1] similar to that used at Brookhaven National Laboratory[2]. This photoinjector supplies a 4.5 MeV/c electron beam which is then further accelerated by a Plane Wave Transformer Linac[3]. The linac brings the beam up to the desired 15-20 MeV/c momentum. After the beam is accelerated it can proceed down either of two beamlines as shown in fig. 1. The transport in the straight beamline consists of the gun, a focusing solenoid, the Plane Wave Transformer, and then a series of quadrupoles to focus into the FEL undulator. The bent beamline is similar except it passes through a dipole then is focused to a horizontal and vertical waist for diagnostics. We present numerical results obtained by using the particle dynamics code PARMELA[4] to model the electron bunch dynamics through the R.F. structures. Also, we do second order TRANSPORT simulations through the beamline using the PARMELA output to study the beam transport through the remaining static elements.

Photocathode R.F. Gun

The R.F. gun is a 1.5 cell π-mode standing wave structure. It operates at the SLAC frequency of 2856 MHz and provides high peak accelerating gradients of up to 100MV/m on the photocathode. The R.F. gun requires 6 MW of power to accelerate electrons to 4.5 MeV/c, which will be supplied by a SLAC XK-5 klystron. The high field in the cathode region minimizes the space charge emittance growth due to the space charge force when the electron beam is non-relativistic. The ultra short electron bunch length can also be easily controlled by adjusting the laser pulse length, thus minimizing the energy spread in the beam and also the nonlinear emittance contribution due to a long bunch length. The photocathode is illuminated with a frequency quadrupled pulse from an Nd:YAG glass laser and can be injected at either a 70° or at $2°30'$ to the axis, which will allow for enhanced photoemission using a polarized laser field parallel to the cathode or ultrashort pulsing, respectively. The cathode will be initially made of copper which has a quantum efficiency $\geq 10^{-5}$.

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Plane Wave Transformer

The Plane Wave Transformer, PWT, which will be placed after the R.F. gun and solenoid is a π-mode standing wave structure which operates again at the SLAC frequency of 2856 Mhz and will be powered by the same klystron which powers the R.F. gun. The PWT is similar to the standard coupled cavity linac structures, accelerating the electrons in successive gaps in a π-mode field. The difference in the PWT is that it is a copper plated aluminum cylinder with washers supported $\beta\lambda/2$ apart along the axis. These washers set up the π-mode structure of the accelerating R.F. fields such that the electrons see a standard CCL field pattern. The power to the accelerating cells propagates in a TEM like mode in the outer radial region of the cylinder in a standing wave pattern which delivers power to each cell. Thus, the outer part of the structure uses the standing TEM mode to deliver and transform the power to the TM_{02}-like mode on the axis to accelerate the electrons.

PLANE WAVE TRANSFORMER

Cell Length [cm]	5.25
Resonant Freq. [MHz]	2856
Cavity Q	36,200
Shunt Impedance [$M\Omega/m$]	104

Linac Simulations

The gun geometry was designed and modeled with the SUPERFISH[5] code to minimize the radial nonlinear fields because any non-linear R.F. fields contribute to the emittance growth. These fields were then used as input for PARMELA simulations. PARMELA simulations were then done to model the space charge effects and also the electron dynamics in the guns' R.F. fields. For a 1nC, 4 picosecond laser pulse PARMELA gives a transverse emittance of 8πmm-mrad. Here the emittance is the transverse normalized emittance given by

$$\varepsilon_x = \frac{\pi}{m_0 c}\sqrt{< x^2 >< p_x^2 > - < x >^2 < p_x >^2} \qquad (1)$$

However at the gun exit the beam has a large rms angular divergence of 25mrad. This divergence occurs because the gun exit acts like a diverging lense since the radial defocusing electric fields in the last cell of the gun are not canceiled. A way to remedy this divergence problem is to place a solenoid at the exit of the gun to focus the beam in the transverse direction. With the solenoid in place the angular divergence can be reduced to zero or made negative, thus allowing the electron beam to be focused into the following linac. However because the static magnetic field of the solenoid penetrates the R.F. gun some interesting additional effects are observed to take place. In order to minimize the transverse emittance at the exit of the gun the initial launching phase of the photo cathode laser pulse must be shifted back in phase to 55 degrees, from its value of 65 without the solenoid. The solenoid also has the interesting effect of compressing the electron bunch length, and reducing the longitudinal emittance. The amount of compression is dependent on the launching phase. However, the transverse emittance increases when the longitudinal emittance decreases. Figure 2. shows the electron bunch longitudinal phase space at the linac exit.

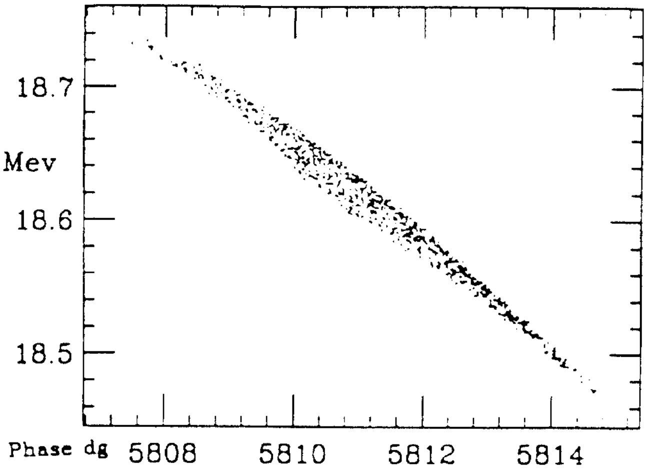

Figure 2: Longitudinal Phase Space

PARMELA LINAC SIMULATION

Laser spot size on cathode [σmm]	3
Laser pulse Length [$psec$]	4
Laser injection phase [$degrees$]	55
Bunch Charge [nC]	1
Trans. Emit $\pi mm - mrad$	8
Energy Spread %	0.2
Peak Current, I [A]	$\geq$ 200
RMS Electron Bunch Length [$psec$]	1.2
Beam Energy [MeV]	18.6

Beam Lines

The FEL[6] beamline was designed using PARMELA to track the beam through the R.F. gun, solenoid, and PWT. The output was then used as the TRANSPORT input to calculate the following beamline to second order. The main consideration for the beam transport is that the electron bunch experience no emittance growth and also that there be a 0.2mm waist at the center of the undulator so as to match well to the FEL[7] optical beam. The TRANSPORT results in figure 3. show the beam line starting at the exit of the linac.

The transport line was designed such that the electron beam has always at least an 8σ clearance in the transverse direction from the beampipe, thus insuring that most of the current will be available downstream. The Plasma

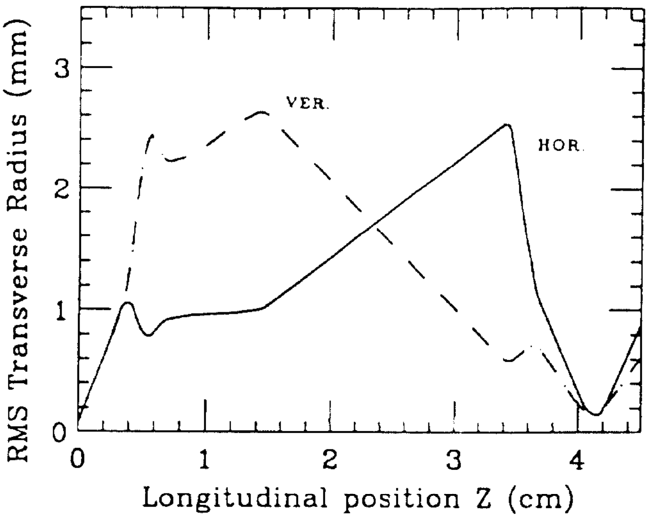

Figure 3: FEL Beam Transport Line

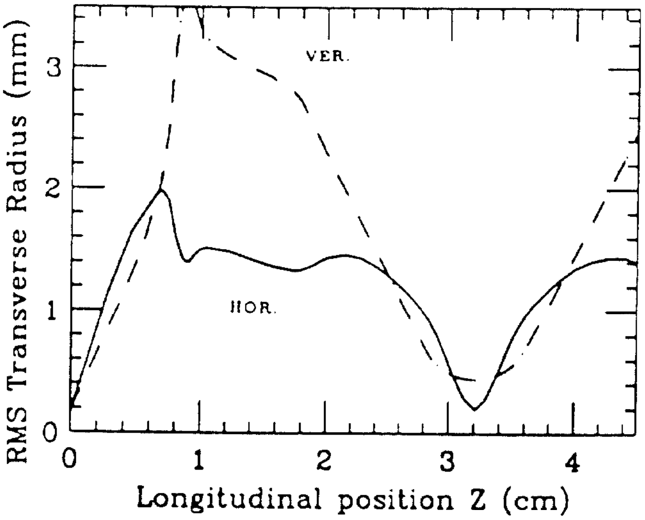

Figure 4: Diagnostic Beam Transport Line

Wakefield Accelerator[8] and diagnostic beamline, shown in figure 4., is designed such that there is a rms beam size of 0.15mm in the midpoint of the bent beamline. This will allow momentum spectrum measurements, by simply measuring beam size at the waist with a resolution of 0.1%.

Beam Diagnostics

Three basic diagnostics will be used to extract information on the beam characteristics. A Faraday cup to measure the current in the beam, CCTV cameras which will measure position and profile of the beam on a phosphorous screen, and for nondestructive position and current measurements we will use stripline monitors. The beam profile monitor consists of a pneumatically actuated screen assembly which can move in and out of the beamline with high precision. The screen itself will be phosphorous coated and also electrically isolated from the beampipe so that it can be used as a faraday cup as well. The bent beamline will be utilized for the momentum analysis, and the beam profile will be monitored at the waist on a CCTV camera to measure the momentum spread. The data aquisition system will consist of a PC to control the accelerator operation and safety interlocks while recording the beam data. A frame grabber will be used to capture the beamprofile, then send it to the PC for analysis and display.

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