Status of RF Photoinjector and PWT Linac at UCLA*

S. Park, N. Barov, S. Hartman, C. Pellegrini, J. Rosenzweig
P. Tran, G. Travish, R. Zhang
Department of Physics, University of California, Los Angeles, CA 90024

P. Davis, G. Hairapetian, C. Joshi, N. Luhmann Jr.
Department of Electrical Engineering, University of California, Los Angeles, CA 90024

Abstract

We report the present status of rf photoinjector and plane wave transformer (PWT) linac for the production of 20 MeV/c electron beam. The photoinjector is a $1\frac{1}{2}$ cell π-mode standing wave structure operating at 2.856 GHz with photoelectrons generated on a copper cathode by 4 ps long laser pulse at 266 nm. Measurements of the beam of photoelectrons are underway at various experimental parameters. The PWT has been tested at low power to investigate its mode structure. An overview of the system, latest data, and future directions are presented here.

Introduction

In recent years, a number of laboratories around the world are either operating photoinjectors or interested in building them. Unlike thermionic cathode, photoinjector requires pulsed power laser as an integral part of the system. Despite complexity and high cost of the laser, the beam quality they provide for free electron laser justifies the efforts.

In terms of the FEL parameter[1] $\rho \sim B_L = I_p/(\gamma\sigma_\gamma)$, where B_L, I_p, γ, σ_γ are longitudinal brilliance, peak current, relativistic factor, and relative energy spread, respectively, the gain length $L_G \sim 1/\rho$, the laser power $P_L = \rho P_b$, where P_b is the beam power. Some other requirements are $\sigma_\gamma < \rho$ and beam emittance $\epsilon < \lambda/4\pi$ where λ is the wavelength of photons out of an FEL.

In the plasma wakefield accelerator (PWFA)[2] situation, attainable gradient $G \sim q/\lambda_p^2$ in the limit $\sigma_r, \sigma_z << \lambda_p$, where $\lambda_p = 2\pi v_b/\omega_p$, and $\omega_p = \sqrt{4\pi e^2 n_0/m_e}$ is the plasma frequency. In either case, large charge per bunch, shorter bunch length, and lower emittance of the beam are required for the better output of the FEL and greater acceleration by the PWFA. In the Particle Beam Physics Laboratory at UCLA, a photoinjector generates high peak current ($I_p \sim 200$A), low emittance ($\epsilon_N \sim 4$ mm-mrad) photoelectron beam to drive a compact PWT for 20 MeV beam energy. This beam of 4 ps pulse length will be used for free electron lasers and plasma wakefield accelerator experiments. The beamline will be enclosed by 3 feet thick concrete wall with inside dimension of 10 feet by 30 feet.

*This work is supported by DOE Grant DE-FG03-92ER-40493 and ONR-SDIO Grant # N00014-90-J-1952.

Photoinjector

The basic feature of our photoinjector is the same as that of Brookhaven[3]. There are minor modifications to the basic design: The axial position of the cathode is adjustable through a micrometer controlled feedthrough, and behind its active surface, the cathode has a groove, around which a beryllium–copper spring is inserted to prevent arcing. Optimal coupling of rf power to the cavity, balancing of electric field between the half cell and full cell, and frequency tuning are performed by adjustment of cathode position, tuner and rf probe at each cell. Once the cavity is under vacuum, the resonance frequency is detuned by deformation due to atmospheric pressure outside, which is compensated by raising the cavity temperature. For the cavity conditioning, a relatively low rf power of less than one megawatt is applied initially. When the number of arcs as seen by abrupt increase in reflected rf power is below one percent of total rf pulses, the rf power level is increased by a half megawatt. This process continues until few arcs are observed at a power level slightly above 6 megawatts. Better conditioning results in less dark current and lower radiation.

Laser

The laser system starts with a mode locked Coherent Antares Nd:YAG laser at 1064 nanometer wavelength. The mode-locker by the same manufacturer outputs 38.08 MHz of frequency continuously. This frequency is also used as a seed signal to be multiplied by 75 times to 2.856 GHz for the RF system. The beam at 1064 nm is passed through a 2.2 km optical fiber for spectral broadening before it enters a Continuum Nd:Glass regenerative amplifier, which is pulsed at 5 Hz by Stanford Research DG-535 pulser, which triggers the RF system simultaneously. The beam from the amplifier is compressed to 4 ps by a grating pair and frequency doubled twice to the wavelength of 266 nm by two

KD*P (potassium dihydrogen phosphate) crystals. This UV beam is transported to the cathode either via window at the photoinjector for a 70 degree angle of incidence or via laser coupling box at 2.5 degrees. The photon energy at the cathode is about 100 μJ. Diagnostics include photodiode, autocorrellator, spectrometer, and streak camera.

RF System

The RF system consists of low level RF, high power RF, and modulator that drives the klystron. The operating frequency of 2.856 GHz is derived from the mode locker frequency of 38.08 MHz by using a 75 times multiplier. Output of this multiplier is amplified to 1 watt cw and, after a power divider, drives a pulsed preamplifier (51 dB gain and up to 1 kW output power) and a number of beam position monitors (BPM). This preamplifier by Pro–Comm consists of one solid state amplifier and three stages of tuned–cavity triode amplifiers. About 300 watts of pulsed rf power is fed into an XK-5 klystron for up to 30 MW of final rf power with 2.5 μs pulse length. This power is divided evenly into two branches by a 3 dB coupler so that one half of it drives the photoinjector through a variable attenuator and the other one half drives the PWT through an attenuator and a phase shifter. The phase shifter sets the phase relationship between the photoinjector and the PWT, whereas the phase between the RF and laser is controlled at the low level cw stage of the rf system by a coaxial phase shifter. Laser pulse and rf waveforms are monitored by a sampling scope.

PWT Linac

The Plane Wave Transformer[4] is a π-mode standing wave structure, characterized by its higher shunt impedance with compact size. It is also simple to fabricate and easy to tune. The PWT is an array of washers along the z–axis in a cylindrical tank. As the rf waves enter the tank, they see the array as a coaxial line and excite TEM–like mode of standing wave. The washers couple this mode outside and transform it to a TM_{02}–like mode in the space between them, which is the origin of the name. We tested the prototype at low power to study its mode structure and coupling efficiency. It has 8 cells with 8 washers extending 41.98 cm inside an aluminum tank of 13.72 cm inside diameter. The washers are supported by 4 rods at the edge of each washer and the entire array is supported by 4 radial stems at each end, their radial positions being adjustable by vacuum feedthroughs. RF power, up to 12 MW in TE_{01} in an S–band waveguide, is fed into the tank through a male Skarpaas flange, with the wave electric field parallel to the PWT axis.

The table below shows its operational characteristics.

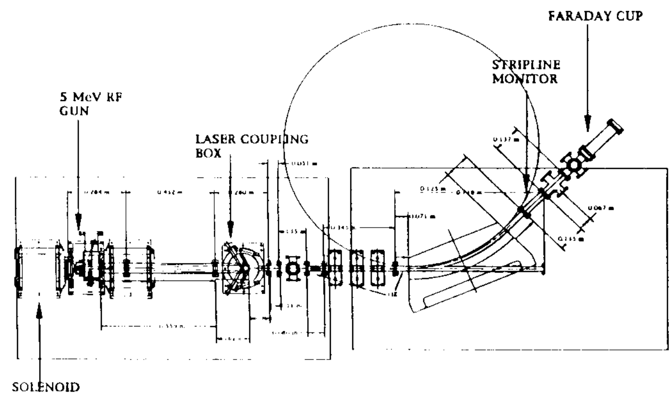

Figure 1: Experimental setup. There are same diagnostics for straight beams too, but not shown here for simplicity.

PWT Parameters	
Frequency	2.856 GHz
Cell Length	5.25 cm
Cavity Q	36,000
Shunt Impedance, ZT^2	104 MΩ/m
Fill Time	2 μS
Energy Gain	15.3 MeV

System Configuration

The entire beamline[5] will be housed in a 3 feet thick concrete wall against neutron outflux, in addition to lead bricks inside for X-ray shielding. The RF gun (photoinjector) is maintained at a constant temperature by the flow of heated water through its water channel for proper tuning. A solenoid magnet at the gun exit focuses the beam; another solenoid is place upstream as a bucking coil. The gun is followed by a 17 inch long drift tube and a laser coupling box. This box has mirrors for 2.5 degree angle of incidence of the laser beam on to the cathode. After this box are a gate valve, flexible coupling, and beam profile monitor. This is a phosphor screen with an aluminum base mounted on a pneumatic actuator. This monitor is followed by the PWT. The whole assembly up to the PWT is place on an optics table. The beamline after the PWT consists of dipoles, steering magnets, quads, and beam diagnostics to deliver the beams to either the FEL or the PWFA. Every phosphor screen is housed in a six-way cross; two are for the beam, and one each for actuator, camera, ion pump, and roughing. Also, beam position monitors are placed next to each phosphor screen, except the one before the PWT, to measure the total charge in a bunch and the position of the bunch on a plane perpendicular to the beam line.

Beam Measurements

For the test of gun together with laser and rf systems, the present beamline is configured as shown in Figure 1 above.

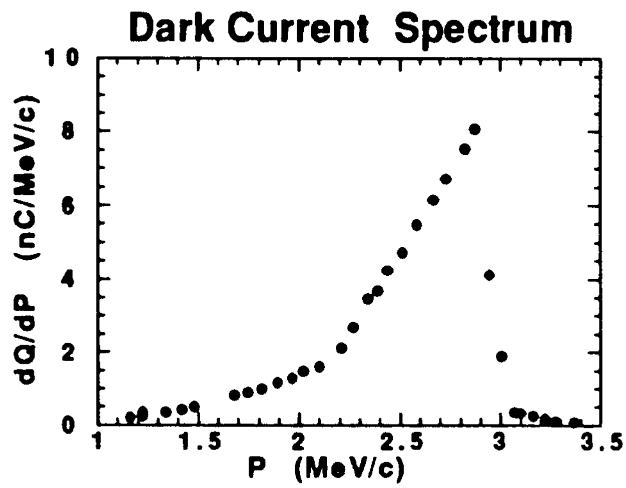

Figure 2: Momentum distrubution of the dark current

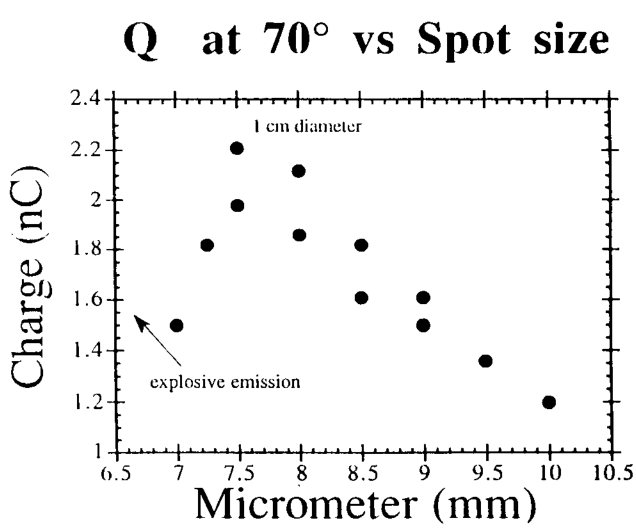

Figure 3: Charge vs. laser spot size.

With this, some preliminary measurements of beam energy, emittance, and quantum efficiency have been made for the beams out of RF gun. Using a calibrated dipole as a momentum selector, beam energy is measured and the gun shunt impedance is calculated to be about 48 MΩ/m. The emittance measurements have been done by measuring beam image size on a phosphor screen changing the current is a quadrupole magnet, which is upstream of the dipole. The phosphor screen is downstream of the dipole. Numerical evaluation of the beam matrix elements resulted in a normalized emittance value of 20 mm-mrad for dark current and 12 mm-mrad for 60 ps photocurrent.

The figures 2 shows a momentum distribution of a dark current. The derivative dQ/dp is peaked at 2.9 MeV/c and drops sharply. The total charge collected at the Faraday cup is 5 nC. The next figure is photoelectric charges plotted against the laser spot size, which must be proportional to the micrometer reading. The decrease in charge at larger than 7.5 mm reading is probably due to scraping off of the laser beam, whereas the decrease at a smaller reading may indicate defocusing of the beam. The angle of incidence was 70 degrees and the energy density at the cathode was believed to be far less than the explosive emission threshold.

A fair amount of work was done to measure the quantum efficiency of the copper cathode at the laser wavelength of 266 nm. The quantum efficiency ranges from 2.7×10^{-5} for 2.5 degree angle of incidence through the laser coupling box, to 1.1×10^{-4} for 70 degree through the laser port at the gun.

A study was done on effect of polarization on photoemission at constant laser energy and the results can be summarized by

$$Q(nC) = 2.58 + 0.79 \sin^2(\theta + 30)$$

where the angle of polarization θ is in degree. Throughout, the charge per bunch was measured by Faraday cup, BPM, and an integrated current transformer (ICT). The charge versus laser energy plot shows a straight line, for up to 1.3 nC at 90 μJ.

Future Directions

The above measurements have been made with a system not optimized. Timing jitter on the part of laser and amplitude fluctuation in both laser and rf are presently larger than the design value. We are working to improve the stability of the system. In conclusion, studies are being done experimentally and theoretically to establish a firm baseline, from which the next generation photoinjectors will evolve and multibunch operation of modified PWT will become practical.

References

[1] C. Pellegrini, Nucl. Instr. & Methods A272, 364 (1988)

[2] P. Chen and J. M. Dawson, "The Plasma Wakefield Accelerators," in *Laser Acceleration of Particles* (Malibu, California, 1985), C. Joshi and T. Katsouleas, Eds., AIP Conf. Proc. No. 130, p. 201

[3] C. Pellegrini, in *High Gain, High Power Free Electron Laser*, R. Bonifacio, L. De Salvo Souza and C. Pellegrini, Eds., (Elsevier, 1989)
Also, K.T. McDonald, IEEE Trans. Electron Dev. ED-35(1988) 2052.

[4] D. A. Swenson, European Part. Accel. Conf. (Rome, 1988) p. 1418

[5] S. Hartman, *et al*, IEEE Part. Accel. Conf. (San Francisco, 1991) p. 2967