A High Duty Factor Electron Linac for FEL*

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Abstract

An 18-MeV, 433-MHz linac capable of operating at 25% RF duty factor (DF) is being commissioned for FEL applications. Comprising a two-cell RF photocathode injector[1] followed by four new multicell cavities[2], the linac is an extension of the photoinjector which previously delivered 5 nC at 27 MHz micropulse repetition frequency, and 25% DF. The system is constructed using equipment from the Ground Based Laser and the Average Power Laser Experiment (APLE). The linac can serve as the driver for an infrared FEL or as the preaccelerator for a higher energy linac driving a visible FEL [3].

Introduction

The High Duty Factor Electron Linac comprises a photocathode injector, accelerator, beamline, associated controls, vacuum, alignment and beam diagnostics. The present layout of the accelerator and beamline is shown in Fig. 1. At this writing, the accelerator and beamline have been aligned and are under vacuum. The accelerator cavities are ready to accept high power RF and only a few controls, beam diagnostics and the drive laser remain to be implemented prior to starting characterization of the electron beam and related experiments[4]. While the RF power system for this accelerator is only capable of operating to 25% DF, the accelerator structures (photocathode, injector and accelerator) have been designed for CW operation.

Photocathode Injector

The photocathode injector (Fig. 2) was designed and tested previously[1]. It consists of a multialkali photocathode and two vacuum brazed OFHC copper cavities. Each cavity is a standing wave structure, operating in the TM_{110}-like mode. The cavities are iris coupled to the RF power. The dynamic resonance is maintained by computer controlled slug tuners located in each cavity. The RF vacuum interface is provided by a high power half-height WR1800 waveguide (1 MW average, 4 MW peak) alumina ceramic window located approximately 1.7 m from the beam centerline and around a 45^{o} bend, to eliminate any direct line of sight between the electron beam and the window.

The drive laser, a frequency doubled , mode locked Nd:YLF system, is injected by an off-axis mirror into the electron beam transport after the second cavity. This laser illuminates a 5 mm FWHM region of the photocathode. The electric field at the face of the photocathode is 26 MV/m. At the exit of the photocathode injector the beam energy is 2 MeV.

Accelerator

The remainder of the accelerator consists of 16 RF accelerating cells constructed as 4 standing wave cavities operating in the TM_{110}-like mode. These cavities raise the final electron energy to 18 MeV. They were originally designed for APLE.

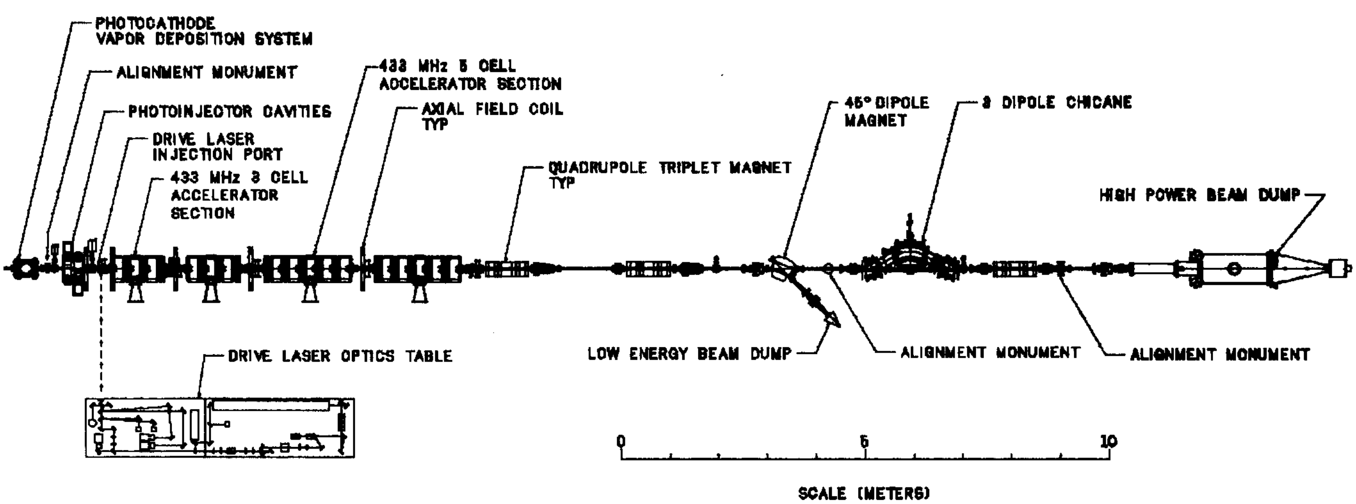

Figure 1. The layout and key elements of the high duty factor electron linac is illustrated in this drawing.

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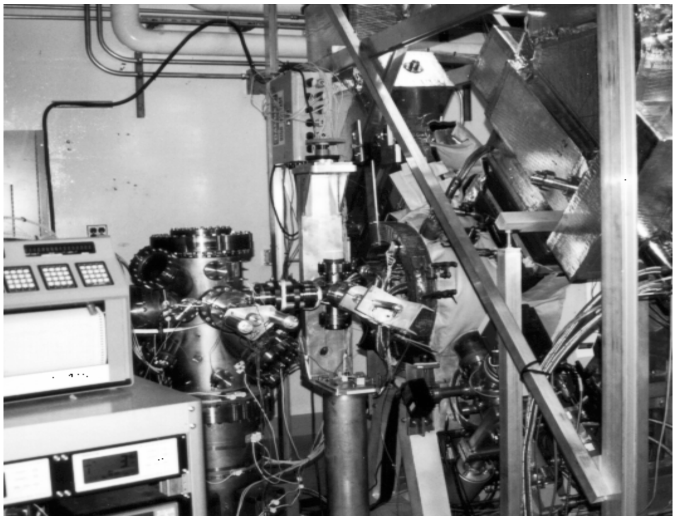

Figure 2. The photocathode fabrication chamber is at the left of the photo. An alignment monument can be seen to the right and immediately to the left of the injector cavities.

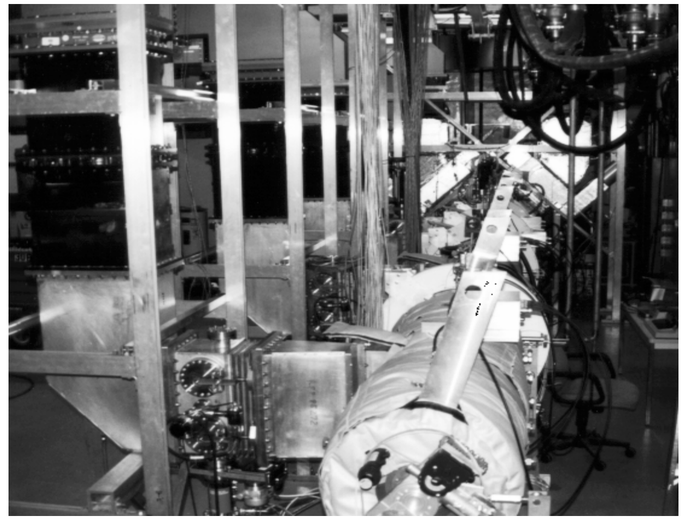

Figure 3. This photograph is taken from the 18 MeV end of the accelerator looking toward the injector. The WR1800 RF waveguide is at the left of the cavities. The bars extending upward to the right of vertical carry the offset alignment targets.

The cavities are constructed from copper plated aluminum cells which are bolted together. The first two cavities each contain 3 cells and the last two cavities each contain 5 cells. RF power is iris coupled into the center cell of each cavity. Dynamic resonance control of each cavity is maintained by two computer controlled slug tuners, one each located in the cells immediately preceding and following the center cell. The RF vacuum interface for each cavity is provided by a full-height WR1800 waveguide (1 MW average, 4 MW peak) alumina ceramic window located 2.4 m from the beam centerline around a 90^{o} bend to eliminate direct line of sight between the electron beam and the windows. Details of the construction and low power RF tests of one of these cavities is reported elsewhere[2]. Figure 3 shows the accelerator and some of its associated equipment.

RF Power

RF power for the accelerating cavities is provided by two 1 MW average, 4 MW peak, 433 Mhz klystrons. The cavities are driven through a system of WR1800 waveguide, hybrid splitters and phase shifters. Phase and amplitude control is accomplished by a Los Alamos GTA[5] RF control system.

The DC power regulator and modulator for each klystron provides DC pulses of up to 115 kV, 10 ms at a pulse repetition of up to 30 Hz. Details of this system are discussed in [6].

Beam Line

The beamline extends from the end of the second 5-cell APLE cavity for 13.7 m to a 1.3 MW high power beam dump. Within this transport are three quadrupole triplet lenses, a 45^{o} dipole magnet leading to a 5 kW beam dump, a magnetic chicane, 8 vertical plus 8 horizontal steering magnet pairs and 12 beam diagnostic stations which will be used to characterize the electron beam, and to conduct various beam conditioning studies. The accelerator beam control is maintained by 7 axial field focusing coils and 5 vertical plus 5 horizontal magnetic steering coil pairs.

Beam Diagnostics

In addition to the beam diagnostics stations in the beam line there are 4 diagnostics stations along the accelerator. The first is located after the photocathode injector and the remaining 3 are located between the four APLE cavities. These diagnostic stations are individually instrumented with a wide variety of devices. In most cases the minimum instrumentation consists of a toroid current monitor and a phosphor or Optical Transition Radiation (OTR) screen. The images produced can be observed with conventional video cameras, intensified gated cameras or a streak camera, depending upon the need of the measurement. Also, in a number of locations nonintercepting beam position sensing detectors are available. The combination of these tools in conjunction with the quadrupole lenses and dispersive elements of the beamline will allow detailed emittance, energy spread, and temporal beam characteristic to be measured.

Vacuum

Vacuum throughout the system is maintained by twelve, 10 cm cryopumps, a 20 cm cryopump mounted on the high power beam dump, two 60 l/s ion pumps, and six titanium sublimation pumps. All of the cavities and their associated vacuum waveguides and the cathode fabrication chamber are provided with provisions for bakeout to 180^{o} C (300^{o} C for the fabrication chamber).

Without bakeout, the injector cavities have been in the low 10^{-9} Torr range and previous experience with these cavities indicate that they will easily obtain the low to mid 10^{-10} Torr range required for long photocathode life after a modest bake. The copper plated aluminum cavities presently are at the required $5x10^{-8}$ Torr vacuum without baking.

Tests were previously conducted on one of the 5-cell cavities. After a 72 hour bake at 180^{o} C, the cavity achieved a base pressure of $5x10^{-9}$ Torr at 20^{o} C. Data collected during these tests on the outgassing rates are well represented by a simple temperature dependant expression

$\mathbf{q} = 5.7x10^{-9} \exp(5.6x10^{-2}T)$ Torr-l/s-cm^2

where T is the temperature in degrees Celsius.

Accelerator Support and Alignment

Three alignment monuments have been installed which are used to establish and maintain the accelerator and beamline alignment. These monuments establish the beam center line and an offset line to check alignment of the accelerator without access to the center line.

The APLE accelerator cavities are supported on a three axis kinematic support. The support was designed so that during alignment the vertical, and horizontal motions of bore sight targets placed in opposite ends of a cavity are independently controlled and uncoupled. This greatly facilitates initial installation and final alignment. The cavities have been aligned to better than the required transverse 0.5 mm and longitudinal 3 mm.

Computer Control

The accelerator, RF system, beamline, beam diagnostics and data acquisition are under computer control. The main computers are two micro VAX II's, which control through CAMAC and GPIB, the various magnets, beam diagnostics, and data acquisition. The vacuum systems are controlled by a local Allen Bradly PLC5 and the RF systems are controlled by VME/VXI crates with imbedded 680x0 processors. The operator interface to the RF system is through a SUN SPARC Station 2.

Conclusions

The high duty factor electron linac for FEL is assembled and undergoing initial checkout prior to preliminary operation of the electron beam which is expected soon. Once reliable operation of the electron beam has been established, it will be characterized with regard to beam quality and intensity. After this, the beamline will be modified to conduct an energy recovery experiment, and a beam bunching experiment in preparation for construction of an FEL.

System Characteristics

Characteristics of the main elements of the system are described in Table 1.

Table I.
DESIGN PARAMETERS OF THE HIGH DUTY FACTOR ELECTRON LINAC

Photocathode Performance:	
Photosensitive Material:	K_2CsSb
Quantum Efficiency:	5% to 12%
Peak Current:	132 amperes
Cathode Lifetime:	1 to 10 hours
Angle of Incidence:	0 degrees
Photocathode Laser Parameters:	
Micropulse Energy:	0.47 microJoule
Energy Stability:	1% to 5%
Pulse-to-pulse separation:	37 ns
Micropulse Frequency:	$27 x10^{6}$ Hz
Gun Parameters:	
Cathode Gradient:	26 MV/meter
Number of cells:	2
RF Frequency:	$433 x10^{6}$ Hz
Final Energy:	2 MeV
Accelerator Parameters:	
Peak Accelerating Gradient:	5.5 MV/m
RF Frequency:	$433 x 10^{6}$ Hz
Duty Factor:	25%
Pulse Format	30 Hz x 8.3 ms
Electron Beam Parameters:	
Emittance (four x RMS):	20 to 40 π-mm-mrad
Charge:	1 to 5 nCoulomb
Energy:	18 MeV
Macropulse Current	0.13 Amps
Micropulse Length:	55 ps

References

[1] D. Dowell et al., "First Operation of a High Duty Factor Photoinjector," Proc. of the 1993 Particle Accelerator Conference, Washington, D.C., 2967 (1993).

[2] A. Vetter et al., "APLE Accelerator Prototype Cavity Fabrication and Low Power Tests," Proc. of the 1993 Particle Accelerator Conference, Washington, D. C., 1075 (1993).

[3] J. Adamski et al., "A Kilowatt Class Visible Free Electron Laser Facility," submited to this conference.

[4] D.H. Dowell, A. Vetter "Magnetic Pulse Compression Using a Third Harmonic RF Linearizer," submitted to this conference.

[5] S.P. Jachim et al., "The Los Alamos VXI-Based Modular RF Control System," Proc. of the 1993 Particle Accelerator Conference, Wahsington D.C., 1154 (1993).

[6] L.M. Knox, "The Successful Design and Development of Multi-Megawatt Radio-Frequency Linac Power Modules for Free Electron Lasers," 1992 Twentieth Power Modulator Symposium, Myrtle Beach S.C., 23 (1992).