INITIAL PERFORMANCE OF LOS ALAMOS ADVANCED FREE ELECTRON LASER*

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Abstract

We report recent results on the high-brightness electron linac and initial performance of the Advanced Free-electron Laser (AFEL) at Los Alamos. The design and construction of the AFEL beamline are based upon integration of advanced technologies such as the high-brightness rf linac, a brightness-preserving beamline with permanent-magnet components, and a pulsed electromagnet microwiggler. With a compact optical resonator, the AFEL will be the first of its kind small enough to be mounted on an optical table, yet capable of providing high-power optical output spanning the near-ir and visible regions.

Introduction

A schematic of the AFEL is shown in Fig. 1. The source of high-current electron pulses is a laser-gatedphotoelectron injector which forms an integral part of a high-gradient 1.2-m long rf linac. The latter is capable of accelerating electrons up to 20 MeV at room temperature and 25 MeV at 77 K. The electrons are produced in 10-ps pulses with peak currents as high as 300 A. These electron pulses are transported in a brightness-preserving beamline consisting of permanent magnet dipoles and quadrupoles. The beamline has three 30° bends. The first bend allows for an input window for the photocathode drive laser beam, the second allows for the FEL output, and the third turns the electron beam into the floor for safety reasons. Additional information on the design physics of the AFEL is presented in other papers at this conference [1,2]..

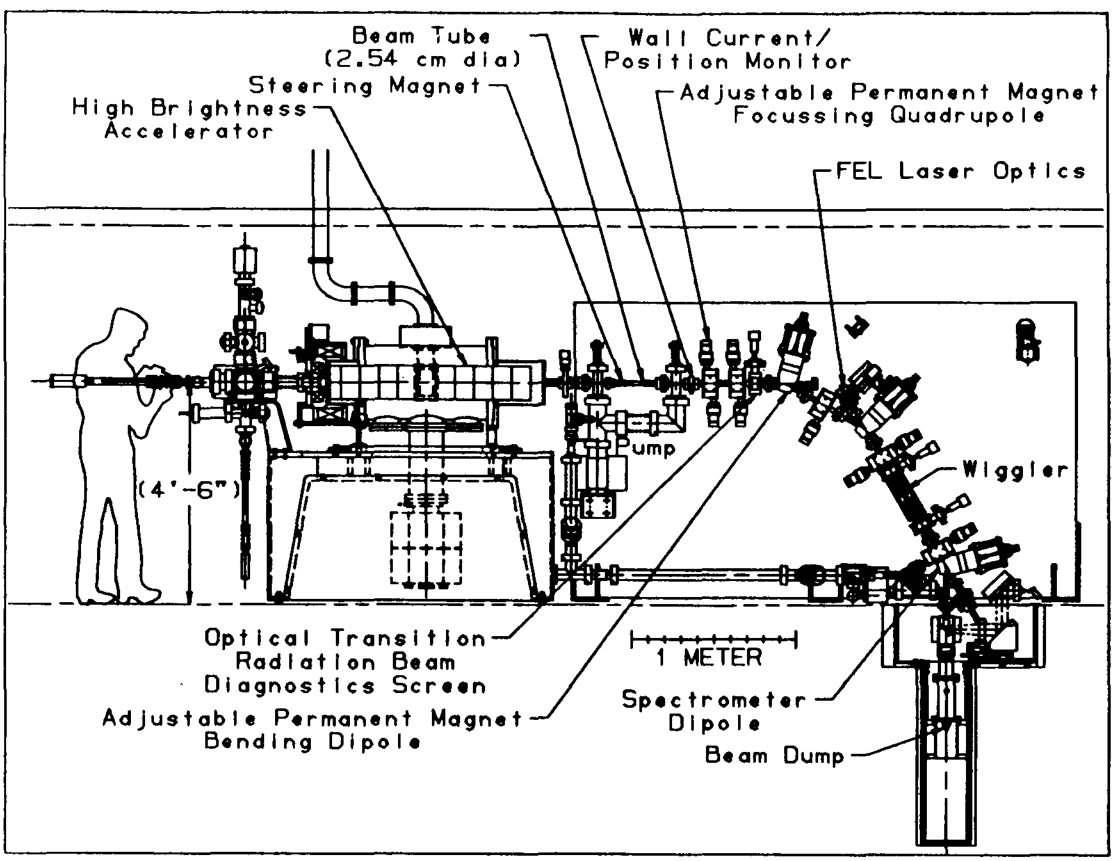

Fig. 1 Schematic of the Advanced Free-Electron Laser.

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Photoinjector

The AFEL photoinjector consists of a K_2CsSb photocathode, located in a high-gradient rf cell which is part of the linac, and a frequency-doubled mode-locked Nd:YLF drive laser. K_2CsSb is used as a photocathode material because it offers high quantum efficiencies, typically in the range of 1 to 5%, when illuminated with 2.3-eV photons. However, this multialkali cathode is very susceptible to poisoning, necessitating a vacuum environment better than 10^{-8} torr. Even in this high vacuum, these cathodes exhibit 1/e lifetimes of the order of 30 hours of run time. In the AFEL experiment, an inserter/transporter mechanism allows photocathodes to be prepared in batches of six in a separate chamber and then transported to the accelerator *in vacuo*. In this manner, a total run time of ~200 hours can be obtained before the cathode six-pack has to be replaced.

The drive laser consists of a cw mode-locked Nd:YLF oscillator operating at 1053 nm and a pulse repetition rate of 108.333 MHz, the 12^{th} subharmonic of the 1300-MHz rf. The oscillator output pulses, nominally 60 ps long, are compressed to 7 ps in a fiber-grating pulse compressor before being amplified in a double-pass amplifier. The latter has two flashlamp-pumped Nd:YLF amplifier rods whose c-axes are perpendicular to one another. This arrangement allows for cancellation of the thermal cylindrical lensing of the individual rods, resulting in an amplified beam with roundness better than 95%. The ir beam is then frequency doubled in a lithium triborate crystal to produce the green output with a typical pulse energy of 10 μJ in a 7-ps micropulse. The amplitude and phase of the photoinjector drive laser are stabilized and synchronized with a low-jitter master oscillator to obtain optimum photoinjector performance.

Linac

The accelerator consists of 10.5 rf on-axis coupled cells, with a maximum accelerating gradient of 26 MV/m[1]. It is powered by a 1300-MHz klystron capable of producing 10 kW average power or 20 MW peak power. The linac has been conditioned by rf glow discharge, high temperature (300°C) bakes and high power rf runs to obtain good photocathode lifetimes and to achieve high peak accelerating fields. The vacuum in the linac is consistently below 10^{-9} torr without beam and increases to the low 10^{-8} torr with beam. A maximum peak rf power of 8.8 MW, corresponding to a maximum design-point accelerating field of 26 MV/m, has been achieved in the linac. With amplitude feedback control, the cavity fill time is reduced from typical values of 2.5 μs down to 1.6 μs. The amplitude feedback control also stabilizes the cavity power to within 1% at the expense of a 20% reduction in cavity power.

Beamline

The beamline is shown in Fig. 2. For compactness and reliability, the variable-field focusing quadrupoles and bending dipoles are made out of permanent magnet. A toroid is used as a calibrated current monitor. Wall current beam-position monitors are strategically located to ensure beam transport through the center of the beamline. Optical transition radiation (OTR) is used for measuring the beam spot size, emittance and energy. There are four aluminized Kapton OTR screens in the beamline with the last screen being part of the spectrometer.

Detailed designs of the permanent magnet quadrupoles and dipoles can be found in reference 2. The quadrupole fields are variable between -0.262 T and +2.15 T, with a resolution of 3 G. The field is reproducible to less than 1 G. The dipole fields are variable between 0.07 T and 0.3 T, with a resolution of 2.3 mG. The B fields of the three dipoles are within 5% of one another.

Wiggler

The high-brightness electron beam is used to excite a 24-period permanent magnet microwiggler with 1-cm periods. Each period consists of two pairs of samarium cobalt magnets whose fields oppose each other and are oriented along the direction of electron beam path (Fig. 3). With a gap of 2.5 mm, the average magnetic field is 0.52 T, giving rise to a peak a_w value of 0.486. Future experiments will employ a pulsed electromagnet microwiggler with 3-mm periods producing a peak a_w as high as 1.4 [3].

Resonator

The AFEL resonator consists of two concave gold-plated copper mirrors with a radius of curvature of 0.699 m. The mirror separation is 1.3836 m, corresponding to 1 micropulse in the cavity. At 3.74 μm, the calculated waists at the center of the wiggler and at the mirrors are 290 and 2858 μm, respectively. The Rayleigh range is 6.9 cm. The upper mirror has a center hole for output coupling. Future experiments, especially those involving visible wavelength operation, will incorporate multilayer dielectric mirrors.

Initial Experiment Results

The beamline is designed to transport an electron beam with peak current in excess of 300 A and maintains an instantaneous rms emittance of less than 2.5 π-mm-mrad and an energy spread of approximately 0.3% [1]. Initial beam experiments have produced a peak current of 65 A at a beam energy of 15 MeV. The beam has been successfully transported through all three bends. Our simulations indicate that with the 24-period permanent magnet wiggler described above, a peak current of 175 A, rms emittance of 2π-mm-mrad, and energy spread of 0.5%, the FEL single-pass small signal gain at 3.74 μm is expected to be 87.5%.

Summary

The Los Alamos AFEL is in its final stage of construction and will be in full operation by early 1993. The high-gradient linac is fully operational and tested at the design points. The beamline has been assembled and

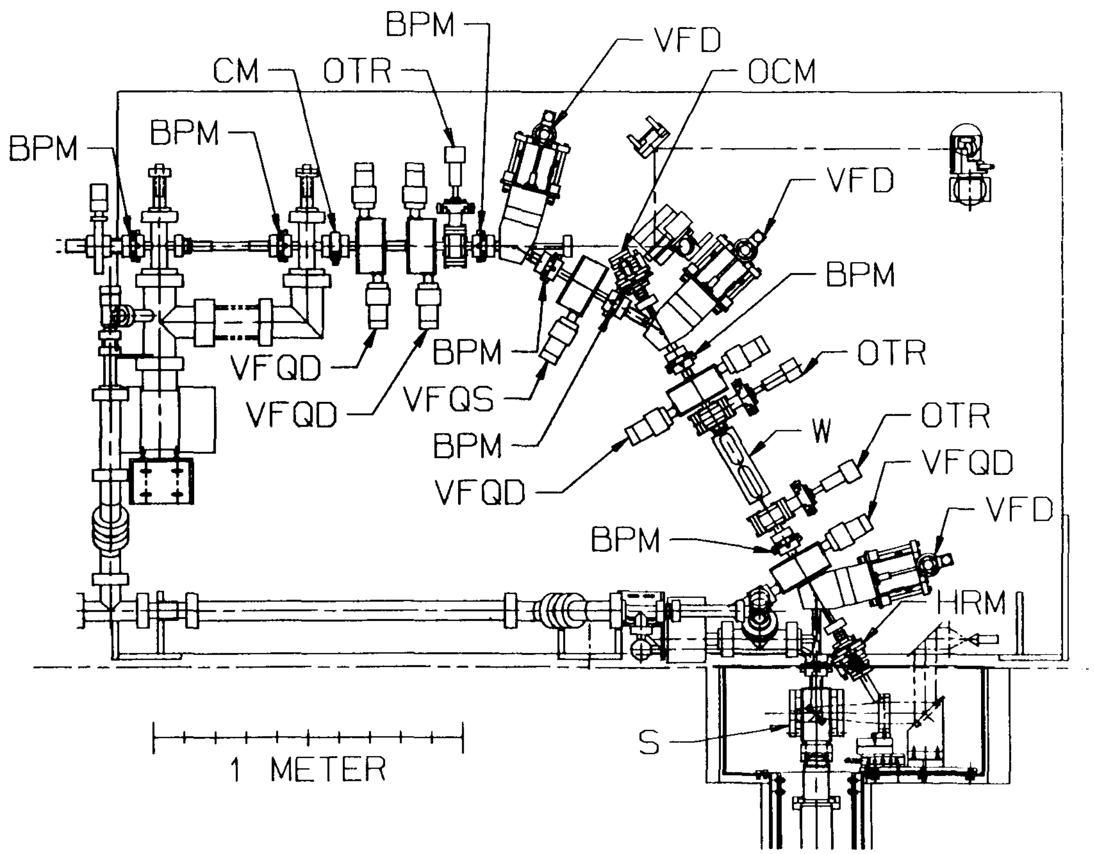

Fig. 2 Layout of the Advanced FEL beamline. BPM: Beam Position Monitor; CM: Current Monitor; HRM: High Reflectivity Mirror; OCM: Output Coupling Mirror; OTR: Optical Transition Radiation; VFQD: Variable Field Quadrupole Doublet; VFQS: Variable Field Quadrupole Singlet; VFD: Variable Field Dipole; S: Spectrometer; W: Wiggler.

tested with beam current, and the beamline magnets have been characterized. Ongoing work concentrates on understanding the beam characteristics and achieving FEL oscillation in the wavelength range between 3 and 7 µm.

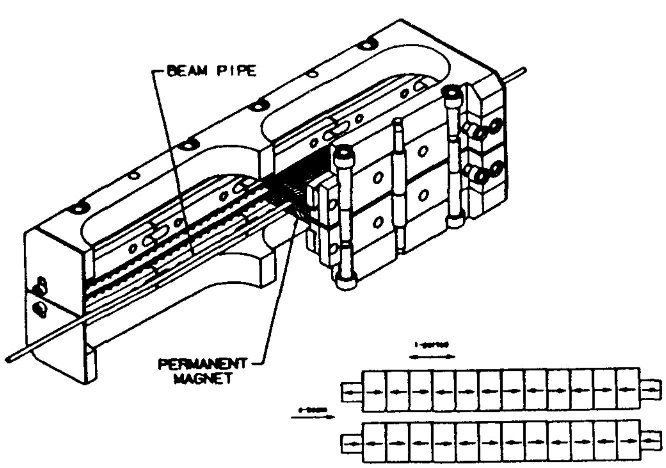

Fig. 3 Schematic of Advanced FEL permanent magnet wiggler.

Acknowledgment

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