DESIGN OF A COMPACT APPLICATION-ORIENTED FREE-ELECTRON LASER*

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Abstract

The goal of the Advanced Free-Electron Laser Project at the Los Alamos National Laboratory is to demonstrate that a free-electron laser (FEL) suitable for industrial, medical, and research applications can be built. This FEL system should be efficient, compact, robust, and user-friendly. To achieve this goal, we have incorporated advanced components presently available. Electrons produced by a photoelectron source are accelerated to 20 MeV by a high-brightness accelerator. They are transported by an emittance-preserving beamline with permanent-magnet quadrupoles and dipoles. The electron beam has excellent instantaneous beam quality better than: 2.5 π mm mrad in transverse emittance and 0.3% in energy spread at a peak current up to 310 A. It is used to excite an FEL oscillator with a pulsed-current microwiggler. Including operation at higher harmonics, the laser wavelength extends from 3.7 μm to 0.4 μm.

Introduction

Since its inception, the free-electron laser (FEL) has demonstrated that it can cover power and wavelength ranges interesting for industrial, medical, and research applications. It will be considered as a tool for these applications if it can be demonstrated that FELs can be efficient, compact, robust, and user-friendly. Demonstration of an application-oriented FEL with these properties is the goal of the Los Alamos Advanced Free-Electron Laser (AFEL). This goal is achievable because of the technological advances in the last 10 years. These technological advances include the integrated-simulation capability, the high-brightness accelerator, the permanent-magnet beam-transport elements, the pulsed-current microwiggler, and the computer-based control system. In this paper, we will describe how the technological advances help us to build an application-oriented FEL.

Integrated-Simulation Capability

The AFEL system (Fig. 1) was designed with integrated simulations[1] to achieve optimal efficiency. In the past few years, we have come to understand how various physical effects affect the design of an FEL system. These physical effects include thermal effect at the photocathode, space-charge effect at low electron energy, multipole rf fields in an accelerating cavity, wakefield effects, and FEL interaction with instantaneous beam emittance. We have also realized that an FEL system should be designed as an integrated system instead of as separate components. In an integrated simulation, the fields due to different physical effects are calculated using various computer codes. These fields are incorporated as external fields in the computer code PARMELA to track a micropulse through the whole system, from the photocathode to the beam dump, to calculate the FEL performance.

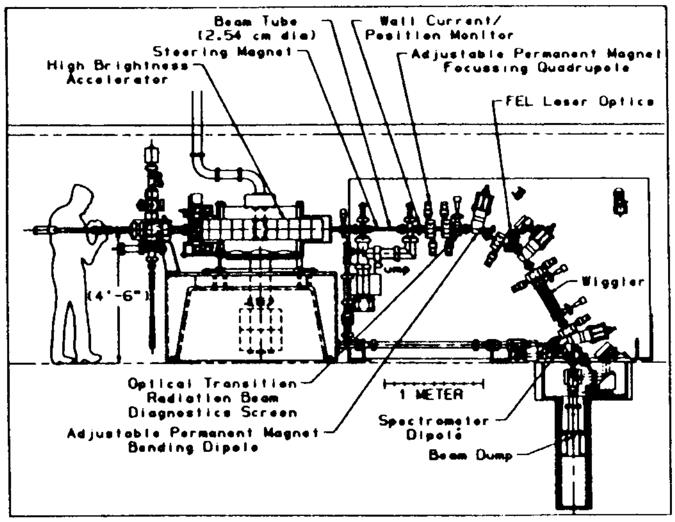

Figure 1: A schematic of the Advanced Free-Electron Laser System at Los Alamos.

High-Brightness Accelerator

A high-brightness beam is the key to achieving high efficiency and short wavelength. The AFEL accelerator[2] (Fig. 2) is designed to produce a beam of transverse emittance of better than 2.5 π mm mrad (rms, instantaneous, normalized) and energy spread of better than 0.3% (instantaneous, rms). This corresponds to a brightness of 10^{13} A/m^2.

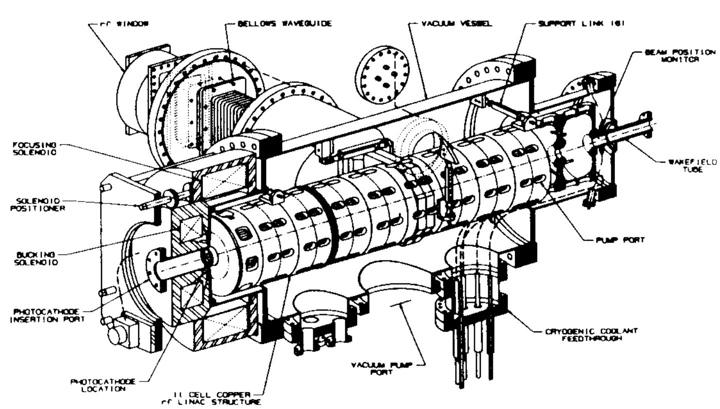

Figure 2: A schematic of the AFEL high-brightness linac.

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A laser-driven photocathode[3] is used as the electron source. Such a photoinjector is necessary for the production of a high-brightness beam for two reasons. First, it can produce high peak current. A current density of 3 kA/cm^2 has been demonstrated at Los Alamos. Second, the time format of the electron micropulse is determined by the micropulse format of the drive laser. A beam buncher, which will cause beam mixing and beam-quality deterioration, is not required.

The accelerator is operated at a field gradient of 25 MV/m. This high field gradient reduces the length of the accelerator to 1.2 m for compactness and minimizes the transverse-emittance growth due to space-charge forces for high brightness. The accelerator is designed to operate at cryogenic temperature (77°K) for improved efficiency.

Permanent-Magnet Quadrupoles and Dipoles

The quadrupoles and dipoles used on the AFEL beam lines are driven by permanent magnets.[4] They have a few advantages compared with electromagnetic devices. They are efficient because they do not need supply current and have no resistive losses. They are simple and compact because they have no resistive loss and require no cooling lines. They have stable fields because there is no jitter in the supply currents. Using stepper motors with high gear ratios, the strength of these devices can be set very precisely.

Figure 3 is the schematic of an AFEL dipole. The maximum field at the gap is 3.5 kG. The field is varied by moving the shunt toward or away from the permanent magnets using a stepper motor. Figure 4 is the schematic of an AFEL quadrupole doublet. By rotating the outer ring of permanent-magnet material, the quadrupole gradient can be varied between -10 to 60 T/m.

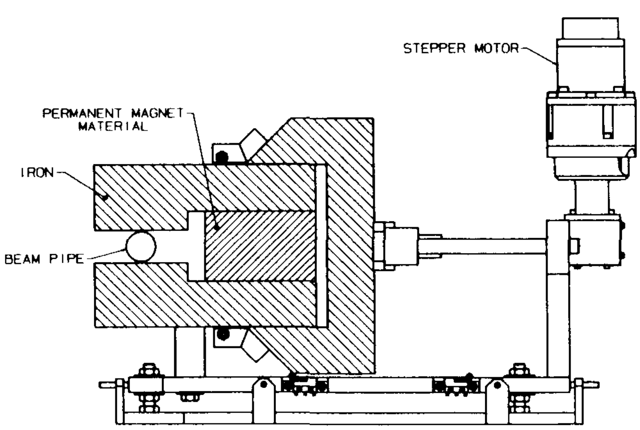

Figure 3: A schematic of the AFEL variable-field permanent-magnet dipole.

Pulsed-Current Wiggler

Figure 5 shows the schematic of a pulsed-current wiggler.[5] It consists of a copper tube with transverse cuts alternating on opposite sides. These cuts force the current to follow a wiggly path, generating a wiggler magnetic-field pattern. The wiggler period is of the order of millimeters. It is smaller than the wiggler period of a permanent magnet wiggler, which is usually 1 cm or larger. By passing tens of kiloamperes of current through such a wiggler, a wiggler field of a few Tesla is possible. The a_w from such a wiggler field is one order of magnitude higher than that achievable using a permanent magnets. The short period and high a_w allow a pulsed-current wiggler to efficiently produce short-wavelength light with a compact low-energy electron source.

The AFEL pulsed-current wiggler has a period of 3 mm. Using a pulsed current of 40 kA, an a_w of 1.4 can be obtained. Such a_w can allow the operation of the wiggler at the fifth harmonic (0.36 μm) with a small signal gain of 150%.

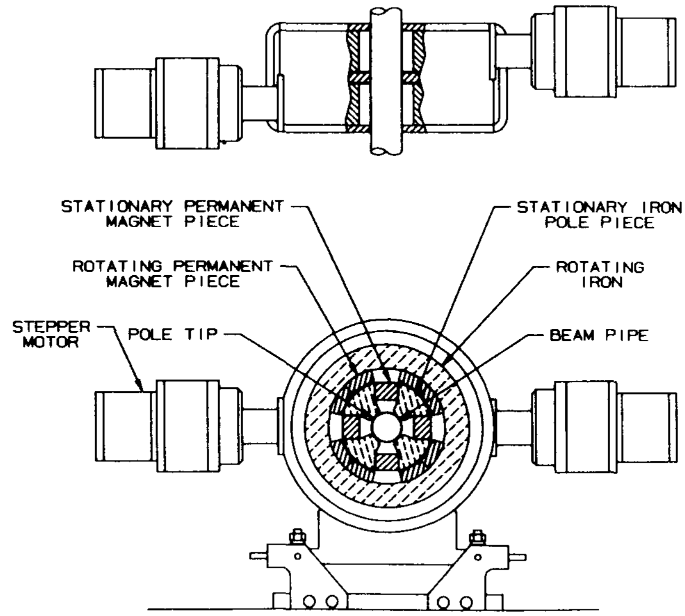

Figure 4: A schematic of the AFEL variable-field permanent-magnet quadrupole.

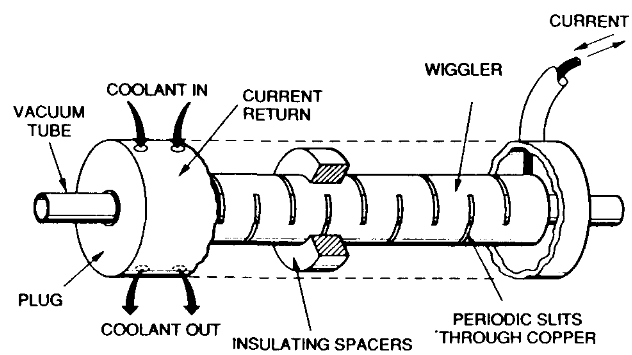

Figure 5: A schematic of a pulsed-current wiggler.

Computer-Based Control System

A computer-based control system has many advantages. A well-designed system can reduce the staffing requirement.

The system can be reconfigured more flexibly when changes of hardware and modifications are made. Control can be added in piecemeal fashion. Different experimental areas can readily communicate through a local-area network. Data can be easily archived and made instantly accessible to various users simultaneously.

The AFEL control system is derived from the Experimental Physics and Industrial Control System (EPICS)[6], which was developed at Los Alamos. Extensive experience with EPICS at Los Alamos and other laboratories ensures a robust and user-friendly control system. EPICS provides a software environment (Fig. 6) to readily develop control software specific for a particular experiment to achieve maximum simplicity and flexibility in operation The operator communicates with the control system using a Sun workstation. The screen display of the workstation is driven by the Operator Interface (OPI). The display is designed and modified with the Display Editor. A database is constructed using the Database Configuration Tool. A system can be monitored with the alarm manager. Specific operating sequences can be implemented readily through a sequencer with programs written in the State Notation Language.

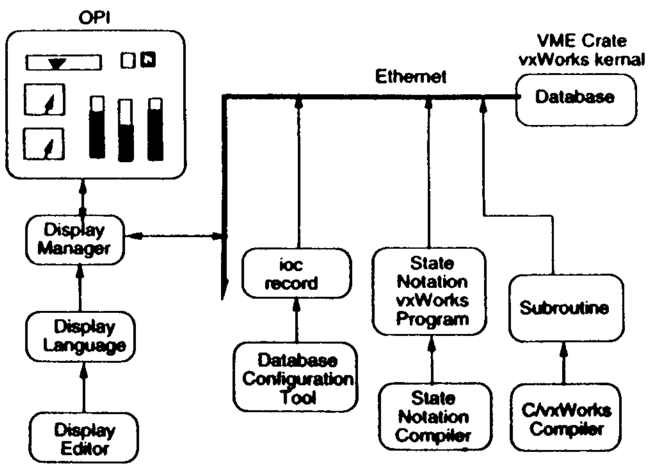

Figure 6: A schematic of the software environment of the AFEL computer-based control system.

Summary

An application-oriented free-electron laser system, the Advanced Free-Electron Laser in Los Alamos, can be designed to be efficient, compact, robust, and user friendly with state-of-the-art technologies.

Reference

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