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Status Report on Jefferson Lab's High-Power Infrared Free-Electron Laser*

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Abstract

Jefferson Lab is building a free-electron laser to produce tunable, continuous-wave (cw), kW-level light at 3-6 μm wavelength. A superconducting accelerator will drive the laser, and a transport lattice will recirculate the beam back through the accelerator for energy recovery. Space charge in the injector and coherent synchrotron radiation in magnetic bends will be present, and the machine is instrumented to study these phenomena during commissioning. The wiggler and optical cavity are conventional; however, significant analysis and testing was needed to ensure mirror heating at 1 kW of outcoupled power would not impede performance. The FEL is being installed in its own facility, and installation will be finished in Fall 1997. This paper surveys the machine, the status of its construction, and plans for its commissioning.

1. Introduction

Thomas Jefferson National Accelerator Facility (Jefferson Lab) is building a cw, kW-level, 3-6 μm free-electron laser (hereafter called the IR Demo). Its purpose is to assess the applicability of the technology for scaling to higher-power devices for potential industrial and defense applications, and to provide a source of intense picosecond infrared light pulses for studies of laser-solid interactions. Wherever possible, the IR Demo incorporates technologies known to be scaleable to high average power.

2. Overview of the Machine

The IR Demo, pictured in Figure 1, comprises a 10 MeV injector and a 32 MeV linac to produce a 42 MeV, 5 mA electron beam for lasing. Top-level beam requirements are listed in Table 1. After lasing, a high-acceptance lattice transports the electron beam back to the linac for deceleration down to 10 MeV, then to a dump. Thus, 75% of its energy is put back into rf power for use in accelerating other electrons, thereby reducing rf power requirements, waste heat, and radiation.

The design of the IR Demo is conceptually similar to that of the first loop in the two-loop ultraviolet FEL design reported at the 16th and 17th International FEL Conferences [1]. To reduce cost and schedule, it incorporates to the maximum possible extent components that are commercially available and/or are standard in Jefferson Lab's nuclear-physics accelerator (CEBAF). The injector comprises a 350 kV cw photocathode gun driven by a modified commercial Nd:YLF laser that is doubled, followed by a copper buncher cavity and a CEBAF-type 1497 MHz superconducting radiofrequency (srf) cryounit that generates an average accelerating gradient of 10 MV/m to boost the beam to 10 MeV. Two commercial 50 kW klystrons power the cryounit. The accelerator uses a full CEBAF-type 1497 MHz srf cryomodule that generates an average accelerating gradient of 8 MV/m to boost the beam to 42 MeV. A commercial wiggler and modified versions of CEBAF's rf system, control system, and safety system are also included. Use of CEBAF-derived components modified for high beam current leverages Jefferson Lab's experience building, installing, and operating the 42 cryomodules comprising its 4 GeV accelerator.

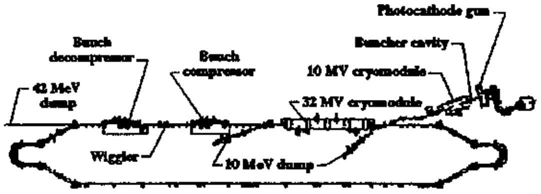

Figure 1. Schematic of IR Demo.

Beam impingement must also be kept low (<5 μA at >25 MeV) to mitigate radiation damage, shielding requirements, and electronic noise. Low beam loss, aided by intrinsically large apertures of srf cavities and by designing large apertures into the electron-transport system, also supports safe hands-on maintenance. The

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recirculation lattice is likewise based on a mature design, that used in the MIT-Bates accelerator. Instabilities arising from fluctuations of the cavity fields are a concern. Energy changes can cause beam loss on apertures or phase oscillations during beam transport with concomitant changes in the beam-induced voltage in the cavities that can lead to unstable variations in the accelerating field. An analytic model of the instabilities, including amplitude and phase feedback, and numerical simulations both suggest that, given microphonic noise of amplitude typically found in CEBAF, the rf control system should provide stable, robust operation [2].

Table 1: Beam Conditions at Wiggler for 1 kW Lasing

Energy	42 MeV
Average current	5 mA
Bunch charge	135 pC
Bunch length (rms)	1 ps @ 135 pC
Peak current	50 A
Transverse emittance (normalized rms)	13 mm-mrad*
Energy spread (rms)	210 keV
Longitudinal emittance (rms)	50 keV-deg
Pulse repetition frequency	37.425 MHz

*allows 3rd-harmonic lasing; 20 mm-mrad permits 3 μm.

The wiggler, manufactured by STI Optronics, is a NdFeB hybrid with 40 periods at 2.7 cm wavelength, operating with a fixed gap of 12 mm to produce K=0.98. The optical cavity is 8 m long with a near-concentric configuration and transmissive outcoupling through sapphire mirrors. Analysis and testing indicates that mirror heating at 1 kW of outcoupled power at 3-6 μm will be sufficiently low not to impede performance [3].

The IR Demo is being installed in its own two-story facility on the CEBAF site. It is located below grade on the first floor, a "rigid-box" concrete structure that "floats" on compacted soil for stability. Six user labs, served by optical beamlines from the FEL below and with a floor space of about 670 m^2, are on the second floor, a steel-framed structure with space for rf power, electronics, and controls. They have low-conductivity cooling water, dry gas, electrical services, chemical hoods, and exhaust vents. Quick vacuum interconnects permit enclosure of the optical beam and transport to any lab, and remotely insertable mirrors can deliver the beam to any station desired. Plans for initial experiments include modification of surface morphology of polymers, glazing of metals for improved corrosion resistance and yield strength, and tests of microfabrication techniques.

3 Technical Risks and Plans

Principal technical risks are injector operation and energy recovery while lasing. Space charge is important along the injector beamline, and the cryounit will be heavily beam-loaded. If necessary, the injector can be operated at twice the planned pulse-repetition rate and half the charge per bunch to mitigate space charge. A real-time transverse-emittance monitor is included in the injector beamline [4]. Experiments with the gun suggest lifetime of the GaAs cathode is a concern for kW-level operation, and we will accordingly explore alternative cathodes and cathode-preparation procedures. Though energy recovery has been demonstrated, the approach has never been implemented with high-power beam. A scraper is located in the first leg of the first recirculation bend as a precaution against beam loss. It is also designed to serve as an excellent energy-distribution and halo diagnostic, in addition to being a safeguard for machine protection.

Coherent synchrotron radiation (CSR) will be present in bends, potentially causing growth in transverse emittance. Simple estimates indicate growths of about 10% in each chicane bypassing the optical-cavity mirrors, and roughly a factor of two in each recirculation bend [5]. This concern motivated placing the wiggler after the linac rather than after the first recirculation bend, resulting in a correspondingly larger machine footprint. However, the calculations carry considerable uncertainty, and the machine is an ideal platform for CSR experiments. Parametric studies of emittance growth in the bunch decompressor following the wiggler and in the first recirculation arc are planned, and developments will be posted to a Jefferson Lab www site [6].

The wiggler location also provides a vehicle for early first light, i.e., 5 μm light at 100 W cw power without energy recovery using a 1.1 mA beam. The IR Demo will incorporate a new power supply for the klystrons driving the cryomodule, enabling them to run at 8 kW versus their 5 kW CEBAF specification. Moreover, the wiggler location provides symmetry in the recirculation arcs and back leg, simplifying energy recovery.

Construction is scheduled to be complete in fall 1997; the FEL Facility is already complete. Target dates are: October for start of injector commissioning, early 1998 for initial data on CSR, spring 1998 for first light, and summer 1998 for high-power operation.

References

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