Performance of the Accelerator Driver of Jefferson Laboratory's Free-Electron Laser*

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Abstract

The driver for Jefferson Lab's infrared free-electron laser is a superconducting, recirculating accelerator that recovers about 75% of the electron-beam energy and converts it to radiofrequency power. It is designed to lase continuous-wave at 3-6 μm at kW-level power. In achieving first light, the accelerator operated "straight-ahead" to deliver 38 MeV, 1.1 mA cw current through the wiggler for lasing at wavelengths in the vicinity of 5 μm. The waste beam was then sent directly to a dump, bypassing the recirculation loop. Stable operation at power levels up to 311 W cw have thus far been achieved in this mode. The accelerator has recently recirculated up to 0.6 mA cw current with energy recovery. In this mode it has lased pulsed and cw at low power. It remains to clean up the transport for high-power cw lasing.

1 Introduction

Thomas Jefferson National Accelerator Facility (Jefferson Lab) recently constructed a cw, kW-level, 3-6 μm free-electron laser (hereafter called the IR Demo) [1] and this summer has been engaged in an intensive commissioning effort. The IR Demo incorporates a recirculating superconducting linac for energy recovery. First lasing [2] was achieved on 15 Jun 98, with 155 W cw power at 5 μm wavelength reached just two days later. This was done without energy recovery; however, on 29 Jul 98 lasing was accomplished with a recirculated beam consisting of 200 μs macropulses delivered at 2 Hz repetition rate while recovering energy from the macropulses. That same day, the IR Demo delivered 311 W cw power without energy recovery. To date, lasing with pulsed beam has taken place at currents up to 2 mA averaged over a macropulse. Up to 0.6 mA cw has been recirculated with energy recovery. The machine has also lased cw at low power (6 W) with recirculation. Plans for the immediate future are to optimize the performance of the machine and begin supporting user experiments. This paper outlines the commissioning sequence and accelerator performance leading to these achievements.

2 Overview of the Machine

The IR Demo, pictured in Figure 1, incorporates a recirculating accelerator comprising a 10 MeV injector and a 32 MeV linac to produce a 42 MeV electron beam for cw kW-level lasing. It is designed to achieve the top-level electron-beam requirements listed in Table 1 of Ref. [1] while transforming 75% of the beam power back into rf power. The design of the machine is also discussed in more detail in Ref. [1]. Beam parameters originally thought to be required for first light differ from those needed for kW power, however, and they are listed in Table 1 below.

First lasing involved operating the machine in the "straight-ahead" mode, in which the beam is deposited in the "42 MeV dump" depicted in Figure 1. Doing so allowed us to achieve the first-lasing milestone before construction of the recirculation loop had been fully completed. Subsequently, as mentioned earlier, the machine was operated in the recirculation mode with pulsed beam, first without lasing, then with lasing, and with energy recovery from the pulses. In this mode, the beam is deposited in the "10 MeV dump" after deceleration through the cryomodule. What follows is a brief description of the commissioning sequence that led to achieving the first-light electron beam.

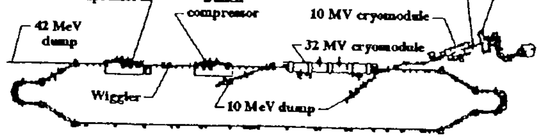

Figure 1. Schematic of IR Demo.

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Table 1: Beam Requirements at Wiggler for First Lasing.

Parameter	Required	Measured
Kinetic Energy	38 MeV	38.0±0.2 MeV
Average current	1.1 mA	1.10±0.05 mA
Bunch charge	60 pC	60±2 pC
Bunch length (rms)	<1 ps	0.4±0.1 ps
Peak current	22 A	60±15 A
Trans. emittance (rms)	<8.7 mm-mr	7.5±1.5 mm-mr
Long. emittance (rms)	33 keV-deg	26±7 keV-deg
Pulse repetition frequency	18.7 MHz	18.7 MHz

3 Photocathode Gun Performance

Testing the gun off-line ultimately yielded bunch charges from 0-120 pC with phase-space parameters that looked to agree reasonably well with PARMELA [3,4]. Consequently the gun was installed in the FEL injection line. The small space between the gun and the cryounit excludes diagnostics, so reasonable confidence in the gun's performance had to be established prior to its installation, and the cited set of experiments sufficed.

To date the gun has been operated in the FEL to a maximum bunch charge of 60 pC in view of the first-light requirements in Table 1 as well as the desire to preserve cathode lifetime. Experience in running the cited gun experiments hinted that cathode lifetime is significantly shorter at higher bunch charges. Experience to date is that the e-folding lifetime of the GaAs cathode is ~10-20 hours at 60 pC, 1.1 mA average current. Cathode lifetime is seen to depend sensitively on the quality of the ambient vacuum, which in turn may be influenced by beam operations via ionization of residual gas and back-bombardment of ions onto the cathode. Available data is too sparse to support a more quantitative statement.

Recently, based on findings of the Lab's Polarized Source Group [5], we began anodizing the outer regions of the cathode wafer to suppress electron emission and halo. Although the benefit has been hard to ascertain conclusively, subsequent operation leading to first light proceeded with easily achievable beam transmission to the straight-ahead dump at 1.1 mA cw, something that had been more difficult to achieve prior to anodization.

4 Key Diagnostics and Accelerator Performance

Diagnostics for the IR Demo include [6]: suites of beam-position monitors, optical-transition-radiation viewers, and beam-loss monitors; two interferometric bunch-length monitors, one (BL1) at the entrance to the linac cryomodule and the other (BL2) just after the wiggler; two multislit transverse-emittance monitors, one (MS1) after the injector cryounit and the other (MS2) at the entrance to the linac cryomodule; two beam-current monitors; and picoammeters at the beam dumps. Key diagnostics that ultimately led to the decision to install the wiggler and try for first light were BL2, a multimonitor emittance measurement using five viewers in the wiggler region, and an energy spread measurement using the dipole magnets and viewer in the second optical chicane. Cleanup of the electron beam proceeded systematically and led to gradual improvement in the six-dimensional properties of the beam. Beam parameters measured at the wiggler location shortly before the 13 Jun 98 wiggler installation were as listed in Table 1. All of them agree with PARMELA to within 10% except the energy spread, for which the measured value was a factor of two higher, and correspondingly so was the longitudinal emittance. The accelerator is capable of generating 48+ MeV beam.

Despite good beam quality at the wiggler, the injector has yet to be fully optimized. Its present setup produces a total beam energy of 9.5±0.1 MeV as inferred from the injection-line dipole strengths, close to the desired 9.65 MeV. Measurements with MS1 yielded a normalized rms transverse emittance of 5.5±0.6 mm-mr, ~30% higher than PARMELA [7]. The beam at MS2 is off-nominal enough that good measurements with MS2 or BL1 have yet to be possible, but the bunch compression, inferred by measuring the M_{55} ($=\partial\phi_{in}/\partial\phi_{out}$) transfer function using a pickup cavity, is close to PARMELA.

5 Status and Plans

The IR Demo achieved first light within six hours from turn-on after installing the wiggler, a testimony to the high quality of the electron beam and FEL systems. It routinely operates with 1.1 mA average current in the straight-ahead mode. The first attempt to take beam around the recirculation loop occurred on 28 Jul 98. In the ten days of machine operations that followed prior to this Conference, we recirculated up to 0.6 mA cw with energy recovery and also lased cw at low power while recirculating. Immediate plans are to clean up the beam transport for kW-level lasing, to begin user experiments, and to measure emittance growth from coherent synchrotron radiation in magnetic bending systems [8].

References

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