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STATUS OF THE LOS ALAMOS FREE-ELECTRON LASER*
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ABSTRACT

Since the initial oscillator experiments were completed last year, the Los Alamos FEL has undergone some major modifications and additions in preparation for the next set of experiments. The laser performance is projected to be substantially enhanced, the rf energy-recovery technique will be demonstrated, and FEL physics measurements will be expanded. The accelerator is now being tuned with very promising performance. The above experiments will be completed during the next year.

1. Introduction

The Los Alamos FEL is now starting the third in a series of experimental setups. The FEL amplifier [1] was operated in 1981 and the oscillator [2] was operated during 1983 and 1984. The results of the oscillator experiment are summarized at this workshop. [3] The setup that is now beginning operation is known as the energy-recovery experiment because of the addition of a large energy-recovery section. This setup will be operated for approximately a year when a higher power, higher efficiency FEL oscillator will be constructed.

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2. Experimental objectives

The objectives of the present set of experiments are threefold:

- Improve the operating parameters of the FEL substantially
- Demonstrate the rf energy-recovery technique
- Continue FEL oscillator physics studies

The first objective of enhanced FEL operation will be accomplished primarily through an improved accelerator and development of optimum wigglers and optical resonators. Peak electron beam currents have been increased by at least a factor of 4 with no loss in beam quality. The average beam current has been doubled. The gain, efficiency, and optical power should improve very substantially with these new parameters. Output powers in excess of 50 kW at 10 μm should be achieved.

After passing through the FEL, the electron beam will have more than 95% of its original power and will still have its microbunch structure. The mix of particles that were, and were not, captured by the photons' deceleration bucket introduces several per cent of energy spread. This spread makes the beam unsuitable for recirculation through the wiggler. However, the overall efficiency of the FEL can be greatly enhanced through recovery of most of the power in the residual electron beam. It appears that the most efficient method of recovering the kinetic energy of the beam in a FEL in this regime is through deceleration in rf-excited linear-accelerator structures. The kinetic energy is thereby converted into rf power that is used to accelerate new beam. A conversion efficiency greater than 99% appears possible. Energy recovery in an electrostatic accelerator used on the FEL at Santa Barbara already has been accomplished. [4] In high-power, high-current rf systems where the beam power is large compared to the structure losses,

overall efficiency improvements (through energy-recovery) greater than a factor of 2 appear feasible.

To continue to improve our understanding of FEL oscillator physics, an extensive experimental program is planned. This program will be addressing, primarily, the issues involved in improving efficiency. An understanding of the production and suppression of the synchrotron sidebands and their effects on efficiency will be pursued, and the problems and opportunities associated with optical beam bending and focusing by the electrons will be studied. Wiggler design improvements will be a major effort. As the accelerator current is increased, the beam-breakup instability measurements will be extended.

3. Experiment description

Extensive modifications have been made to the FEL oscillator to enhance performance. The buncher system was replaced to provide higher beam currents with improved quality, the rf system was moved and overhauled to improve performance and reliability, and the energy-recovery components were added.

The improved accelerator performance will be accomplished primarily through the new injector. The original injector [5] suffered from multipactoring in the first subharmonic buncher and a lack of solenoidal fields over the first linac tank, which limited the peak current to 50 A with an emittance of $2.5 \pi \cdot \text{mm} \cdot \text{mrad}$. Only one subharmonic buncher (TiN-coated stainless steel) and a fundamental buncher attached directly to the linac are now used. A 700-G solenoidal field extends over half of the first linac tank (up to 4 MeV). Simulations of the new injector

indicate that peak currents of over 150 A with 1 mm-mrad should be achieved.

The energy-recovery experiment will use decelerator structures that are separate from the accelerator to provide maximum experimental flexibility. Variable rf bridge couplers will facilitate the rf power transfer over a wide range of deceleration values. [6] The energy-recovery parameters are listed in table 1 and its layout is shown schematically in fig. 1. The major new energy-recovery components added to the oscillator are an isochronous return beamline, two side-coupled decelerator tanks, and two variable bridge couplers. Each accelerator/decelerator pair is excited by a common klystron with gradient ratios determined by the bridge coupler. The 180° bend is mounted on a translation table to adjust the beam path for the proper decelerating phase angle.

4. Status of experiments

The accelerator parameters are now being measured before starting the initial lasing experiments. With the system operating at 20 MeV with peak currents of 175 A (four times greater than previous typical operation), the beam quality appears to be superior to earlier low-current measurements. The long low-current tails on the micropulses during previous operation are now absent, which should enhance the lasing efficiency. The operational reliability of the rf system has been greatly improved.

The first experiments will start next month. The enhanced lasing parameters due to the improved accelerator will be evaluated first. Then the energy-recovery technique will be studied and will be followed by FEL oscillator physics studies into next summer.

The next set of improvements are now being designed. These will involve further efficiency improvements and another order-of-magnitude increase in power. The wavelength will probably remain at 10 μm .

Acknowledgments

The Los Alamos FEL program was conceived by and is carried out under the general leadership of C. A. Brau. The operation of the FEL oscillator experiments is directed by R. W. Warren. The optical measurements are the responsibility of B. E. Newnam. Subsystems contributions are made by the following: J. S. Fraser and L. M. Young, injectors; W. E. Stein, L. M. Young, and G. Spalek, accelerators; M. T. Lynch, W. E. Stein, C. Friedrichs, and P. J. Tallerico, rf systems; R. W. Warren, wiggler; J. S. Fraser, R. L. Sheffield, W. E. Stein, and A. H. Lumpkin, electron diagnostics; B. E. Newnam, J. E. Sollid, and T. A. Swann, optics; and R. K. Cooper, J. C. Goldstein, B. D. McVey, and H. Takeda, theoretical support. The operating support of O. R. Norris, T. O. Gibson, and M. C. Whitehead is crucial. The mechanical support is directed by B. M. Campbell, P. M. Giles, L. D. Hansborough, D. J. Liska, F. E. Sigler, and R. L. Stockley. The electronic support is led by D. C. Stephens. The concerted efforts by this team are gratefully acknowledged by the author.

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Figure caption

Fig. 1. Layout of FEL oscillator with energy recovery:

(1) FEL oscillator operating at increased peak and average currents, (2) Isochronous 180° bend on translation table, (3) Isochronous 60° bend, (4) Two 1.8-m decelerator (energy-recovery) sections, (5) Two variable rf bridge couples, (6) Beam dump for 3-10 MeV beam, and (7) 20-MeV diagnostics.

Table I

Improved operating parameters

	Oscillator <u>experiments</u>	Energy-recovery <u>experiments</u>
Macropulse duration (μ s)	100	100
Micropulse repetition rate (MHz)	21.7	21.7
Micropulse duration (ps)	40	25
Peak current (A)	50	150
Average current (A)	0.05	0.10
Emittance (π •mm•mrad)	2.5	1
Deceleration (MeV)	0	10-18
Copper losses (MW)	2.7	4.5
Beam power (MW)	1.0	2.0
Recovered power (MW)	0	1-1.8
Optical power (kW)	6	>50