Status Report on the NIST-NRL Free-Electron Laser*

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A free-electron laser (FEL) user facility is being constructed ~~at the National Institute of Standards and Technology (NIST) in collaboration with the Naval Research Laboratory (NRL).~~ The FEL, which will be operated as an oscillator, will be driven by the 17 MeV to 185 MeV electron beam of the NIST continuous-wave racetrack microtron. Anticipated performance of the FEL includes: wavelength tuneable from 200 nm to 10 μm; a continuous train of 3-ps pulses at either 16.5 or 66.1 MHz; and average power of 10 W to 200 W. Construction of the RTM will be completed in January, 1991. ~~The~~ 3.64-m-long undulator is assembled at the factory and is scheduled to be delivered in October, 1990. The measured rms field error is 0.6%, which is sufficiently small for good gain. Due to the broad tuning range, the use of lasers to align the cavity end mirrors is impracti~~cal~~. With a full-scale model of the 9-m-long optical cavity, we have developed a method of aligning the mirrors to the required accuracy using white light and an autocollimator/telescope. We have performed three-dimensional simulations of performance including the effects of the electron beam (emittance, pulse length and shape, and timing jitter), undulator field errors, and cavity losses. These calculations predict adequate gain for lasing across the full wavelength range. Additional calculations are underway to predict the performance at saturation. (KT)

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1. INTRODUCTION

We are constructing an FEL user facility, shown in Figure 1, at the National Institute of Standards and Technology (NIST). Unlike other FELs, this one will be driven by a continuous electron beam from a racetrack microtron (RTM). The electron beam, variable in energy between 17 and 185 MeV at an average current of 550 μm, will make a single pass through the FEL undulator. When it begins operation in 1992, the FEL will provide a continuous train of picosecond light pulses at high average power (typically 100 W) at any wavelength from 200 nm to 10 μm, a combination of properties that will allow researchers to perform experiments that are not feasible with other light sources. Table 1 gives the predicted properties of the light beam.

The design of this facility was presented in detail at the 1989 FEL Conference [1]. In the past year the design was reviewed by an outside panel of FEL and accelerator experts [2], who found no reason to doubt it will work. In this paper we present the plan and status of the facility construction project. Funds are pending for completion of the FEL User Facility, and the plan presented assumes full funding.

2. PROJECT PLAN

Construction of the RTM will be completed by January, 1991, and the undulator will be installed and tested by March. The system to transport the electron beam from the RTM to the beam dump after the undulator will be also installed by March. Following the completion of RTM beam tests in the summer, the present injector will be replaced with a new one to provide adequate peak current for lasing (2-4 A). Simultaneously, the laser cavity, the magnets to guide the electron beam around the upstream cavity mirror, and a system to transport the light beam to the diagnostic station in the FEL User Area will be installed. FEL commissioning will begin in the spring of 1992, and operation for users will begin that autumn.

3. ELECTRON ACCELERATOR AND BEAM TRANSPORT

The RTM is designed to recirculate the electron beam, injected at 5 MeV, through a 12-MeV linac up to fifteen times. Microwave power for acceleration is provided by a single, 500-kW klystron that operates in the continuous-wave mode at 2380 MHz. The beam may be extracted after any number of recirculations to obtain electron energies from 17 MeV up to 185 MeV in steps of 12 MeV. Operating with a single pass through the linac, the RTM has produced a 17-MeV beam with a full energy spread of 18 keV, and a normalized emittance of 2.4 μm for 95% of the beam [3]. These results surpass the design goals of 40 keV and 10 μm.

All components of the beam recirculation system are on hand; installation is underway and will be completed by January, 1991. A new, reliable klystron power supply that is under construction is scheduled to be installed in November, 1990. The system to transport electrons from the RTM to the FEL is under construction.

A new control system for the RTM and beam transport system has recently been installed. It uses modular, commercial hardware (workstations, LANs and CAMAC) and software developed at CEBAF [4] to facilitate development and maximize reliability. Already partially connected to the approximately 1000 devices on the RTM and beam transport system, it can be expanded readily to include the FEL Facility - see Figure 2.

The present injector produces a continuous beam of 5-MeV electrons in

3-ps-long micropulses at 2380 MHz with a peak current of approximately 0.07 A. Because this peak current does not provide adequate gain for the FEL, we have designed a new injector that will supply 3-ps bunches with a peak current of up to 4 A [5]. The new injector, shown in Figure 3, will produce a continuous electron beam at either the 36^{th} or the 144^{th} subharmonic of the accelerating frequency. We have ordered the pulsed, thermionic electron gun from a commercial supplier and are designing the other components of the high-current injector.

We are exploring RTM operation with a subharmonically-bunched beam theoretically. Two independent studies [6] indicate that the time-averaged threshold current for beam breakup with 15 passes of subharmonically-bunched beam through the RTM lies between 0.5 mA and 1 mA. Since this is near the maximum planned operating current, further work is in progress to determine the threshold more accurately and to study its dependence on RTM focussing strength.

4. UNDULATOR

The planar, hybrid undulator consists of two halves of 65 magnetic periods each, with 2.8 cm per period. The magnetic field can be varied independently in the two halves up to a maximum peak value of 0.54 T by adjusting the gap and its taper. Both halves will be used together for all but mid- and far-infrared wavelengths, where just one half will be used to reduce diffraction losses.

The undulator is completely assembled at the factory, including: a remotely-operated system to adjust and monitor the gaps, tapers, and steering coils; vacuum chambers; and a magnetic measurement system. The manufacturer has measured the magnetic field and confirmed that it meets the specifications for peak value, harmonic content, and dependence on the horizontal coordinate. The rms field error must be no more than 0.5% of the peak field. The manufacturer has reduced the rms error in the first half assembled from 0.8% to 0.65%, and the initial value for the second half assembled is 0.75%.

The manufacturer is making good progress on reducing the error to 0.5% in both halves of the undulator. We are meanwhile analyzing the consequences of the measured errors on performance in two ways. First, we have used computer programs supplied by Brian Kincaid [7] to calculate that the measured field errors in the first half would reduce the spontaneous emission amplitude by no more than a few percent from the value predicted for a perfect field. This implies an acceptably small reduction in gain. Second, we are modifying the FEL simulation code SHERA to include the measured field data. This work is reported in another contribution to this Conference [8]. The manufacturer will install the undulator in its final position late in 1990 and will then repeat the field measurements.

5. OPTICAL CAVITY

The linear optical cavity will be 9.069 m long. The area has been cleared and is ready for installation of the cavity. Pedestals to support the cavity end-mirrors have been mounted on the subfloor, which sits on bedrock. The measured vibration on the pedestals is less than 10 $\mu m/s^2$.

We are designing chambers for the end-mirrors. Each will hold up to seven mirrors in vacuum and will permit them to be aimed, displaced transversely and longitudinally, and changed in vacuum. The mirrors will consist of multilayer dielectric coatings on transparent substrates, which we expect to work from 300 nm to 10 μm. We are calculating thermal distortion of the mirrors from absorption, and preliminary results are encouraging.

Using a 10-m-long folded cavity, we evaluated several mirror alignment systems and selected and ordered a white-light autocollimator/telescope system that will work throughout the broad FEL wavelength range.

6. FEL PHYSICS

Extensive three-dimensional modelling of this FEL [9] predicts adequate gain at all wavelengths. The modelling includes diffraction losses and the following electron-beam characteristics: 3-ps pulse length, varying pulse shape, phase jitter, energy spread, and emittance. Ongoing calculations include performance at saturation, harmonic production, and, as already mentioned, measured undulator field errors.

7. USER FACILITY

The User Area has been cleared of old equipment and is awaiting refurbishing. Several workshops for potential users were held in the past year. These workshops have generated conceptual designs for four initial research stations: Laser Diagnostics and Radiometry; Raman and Fluorescence Spectroscopy; Photochemistry and Photobiology; and Clinical. We have received serious verbal or written expressions of interest from one or more scientists in seventeen institutions outside our own.

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FIGURE CAPTIONS

Figure 1. Plan View of the NIST-NRL FEL Facility.

Figure 2. Block diagram of the control system for the NIST-NRL FEL Facility.

Figure 3. Schematic diagram of the High-Current Injector for the NIST-NRL Free-Electron Laser.

Table 1. NIST-NRL FEL Anticipated Performance.

Wavelength	200 nm - 10 μm
Average power	10 - 200 W
Pulse width	3 ps
Repetition rate	16.528, 66.111 MHz
Peak power	50 - 1000 kW
Peak energy	0.1 - 3.0 μJ
Photon flux (1-mm diameter spot)	10^{25} - $2 \cdot 10^{27}$ phot cm^{-2} s^{-1}
Photon fluence per pulse (1-mm spot)	$3 \cdot 10^{13}$ - $6 \cdot 10^{15}$ phot cm^{-2}
Spectral resolution	$1.3 \cdot 10^{-4}$ - $6.7 \cdot 10^{-3}$
Polarization	Linear
Spatial mode	TEM_{00}
Beam diameter at waist (at 1/e amplitude)	0.4 - 1.6 mm
Beam divergence (full angle)	0.3 - 5 mrad

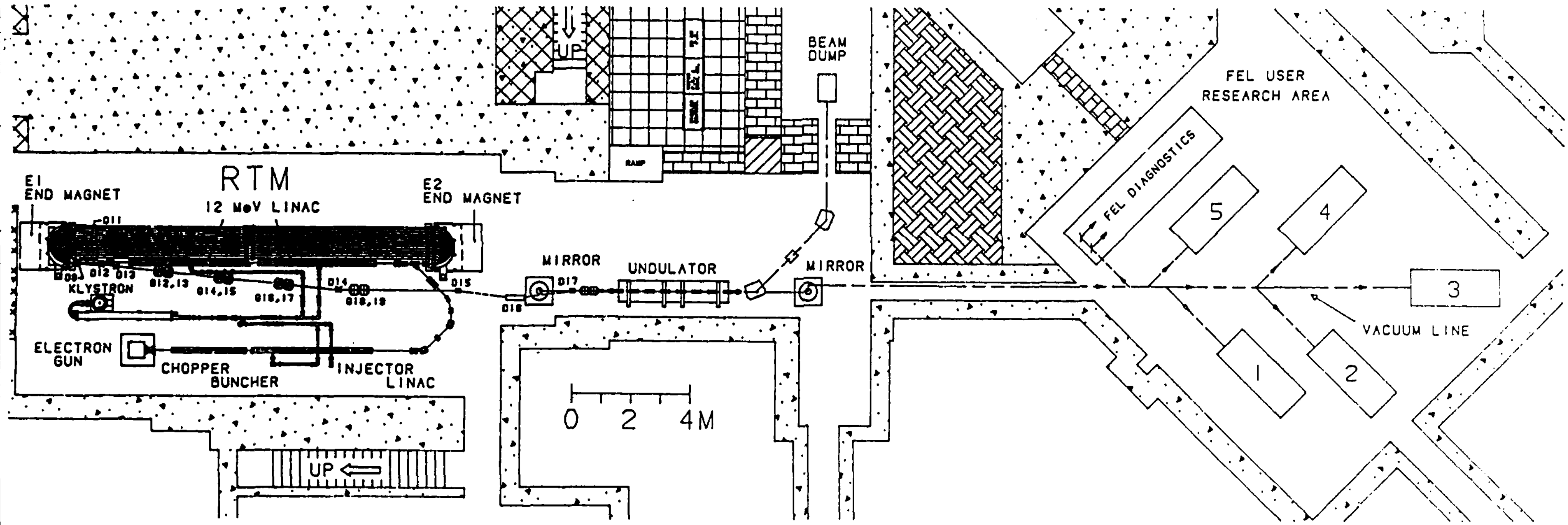
E1
END MAGNET
RTM
12 MeV LINAC
E2
END MAGNET
KLYSTRON
ELECTRON
GUN
CHOPPER
BUNCHER
INJECTOR
LINAC
MIRROR
UNDULATOR
MIRROR
BEAM
DUMP
UP
UP
RAMP
0 2 4M
FEL USER
RESEARCH AREA
FEL DIAGNOSTICS
VACUUM LINE
1
2
3
4
5

Figure 1

RTM/FEL CONTROL SYSTEM

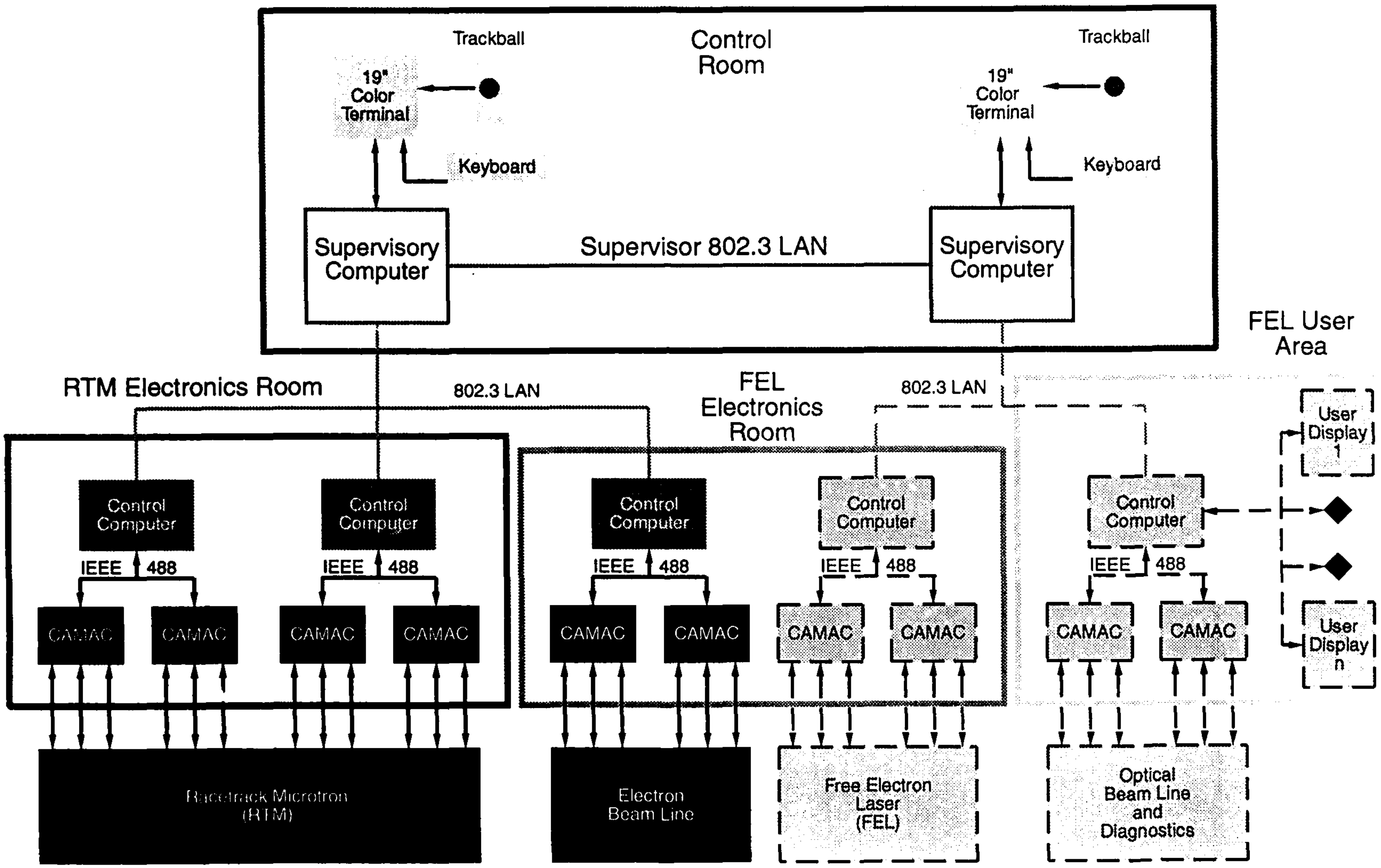

Figure 2

HIGH CURRENT INJECTOR

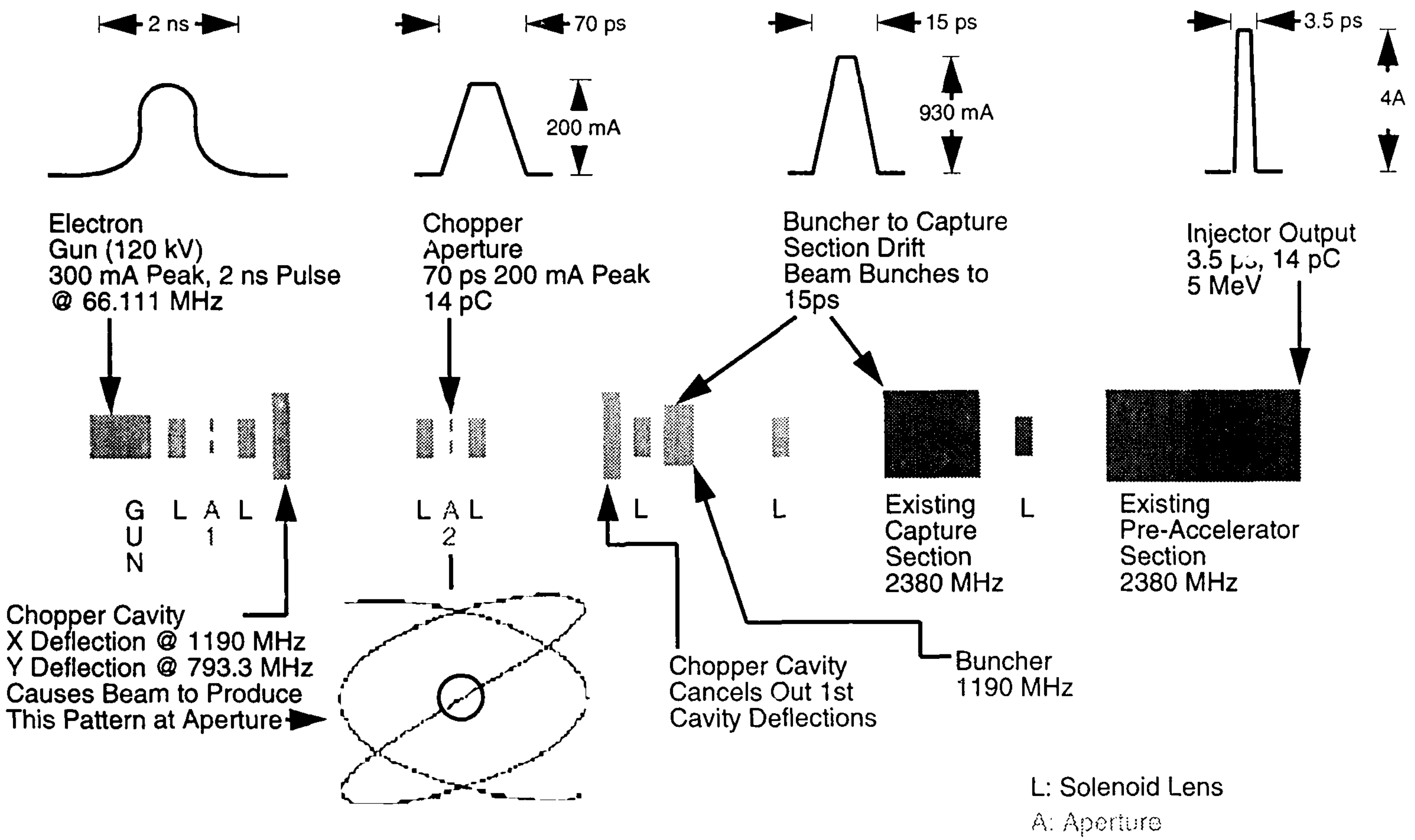

Figure 3