A KILOWATT CLASS VISIBLE FREE ELECTRON LASER FACILITY*

J. L. Adamski, D. H. Dowell, T. D. Hayward, C. G. Parazzoli, and A. M. Vetter
Boeing Defense & Space Group, Seattle, WA 98124 USA

ABSTRACT

The design for a potential free electron laser (FEL), driven by a 120-MeV linac capable of generating 0.1-A macropulse average current beams at a duty factor of 0.6%, is described. The accelerator will employ a photo-injected, 18-MeV, 433-MHz linac as an injector [1], followed by a 1300-MHz longitudinal phase space "linearizer" [2], a magnetic buncher, and seven sections of 1300-MHz, pulsed traveling wave linac structure. Pulse lengths of 7 ps will be attained with minimal distortion of the pulse profile and normalized 90% emittance of 30 ± 10 π-mm-mr. The magnets used to transport the beam from the linac to the FEL centerline, the wiggler, and the optical resonator will be reclaimed from previous FEL demonstration experiments.

I. A NEW HIGH POWER FEL USER FACILITY

A. Introduction

A design has been developed for a powerful, ultraviolet (UV)-to-infrared (IR) wavelength FEL that can be rapidly completed in the USA/SSDC high average power FEL laboratory at Boeing. The laser design is shown in Fig. 1. A high duty factor electron accelerator is already under construction and is scheduled for test in 1995. The remainder of the laser would be assembled utilizing existing inventory from the SDIO ground-based laser program. This new laser can be ready for test in mid-FY96. The operational characteristics of the laser and its principal subsystems are given in Table 1.

Table 1. Kilowatt FEL Parameters

FEL Output		
Laser wavelength	0.2-4	μm
Peak laser power (0.6 - 0.8 μm)	150	kW
Avg laser power (0.6 - 0.8 μm)	1	kW
Peak electron beam power	12	MW
Avg electron beam power	70	kW
RF System		
Macropulse length	200	μs
Macropulse rep freq	30	Hz
Macropulse duty factor	0.6	%
Electron Beam		
Electron beam energy	120	MeV
Macropulse avg current	0.1	A
Macropulse avg e-beam power	12	MW
Average electron beam power	70	kW
Micropulse		
Micropulse rep freq	27.08	MHz
Micropulse charge	3.5	nC
Micropulse length	7	ps
Micropulse avg current	500	A
Optical Cavity and Wiggler		
Optical cavity length	38.74	m
No. circulating optical pulses	7	
Wiggler length	5	m
Wiggler period	2.18	cm
No. periods	220	
Peak wiggler field	1.0	T
Wiggler parameter (rms)	1.31	
Taper	10 step adjustable	
Extraction	1.4	%

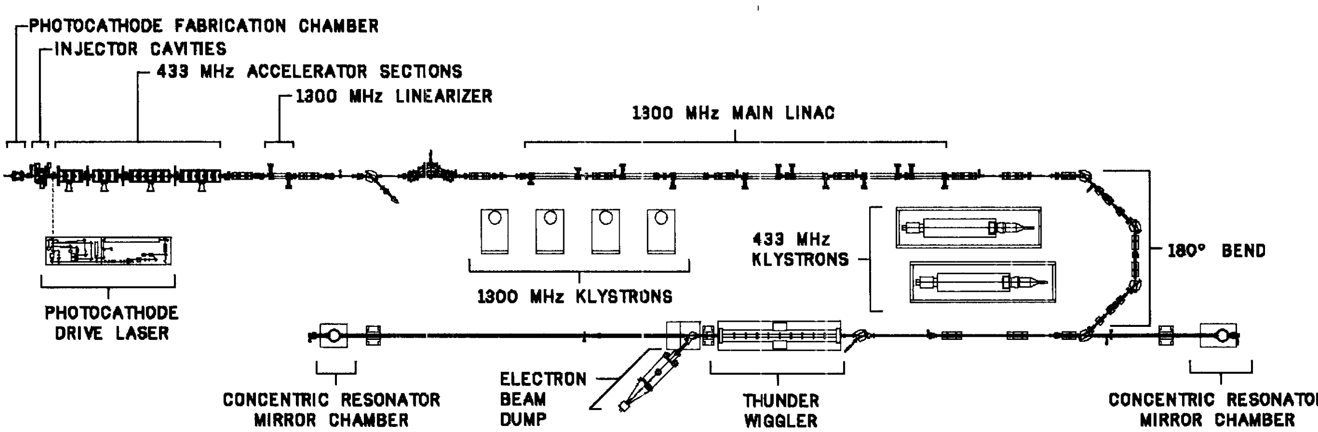

Figure 1. High Power Ultraviolet-Infrared FEL

*Work supported by USA/SSDC under Contract DASG60-90-C-0106

The first operation of the laser will be at visible wavelength. The laser wavelength range can be extended to approximately 4 μm and laser operation on the third harmonic will allow UV wavelengths.

The laser and laboratories will be contained within a 40,000 ft^2 dedicated FEL research complex built with Boeing corporate funds. The FEL facility includes a 12 MW electric power substation, DC power vault, accelerator building with an upper radiation-shielded floor with laser laboratories, and general purpose laboratory space for users. The facility also includes six separate megawatt level thermal control systems for the experiments, full safety systems, and computer control and data equipment.

The 1 kW tunable free electron laser described in this paper builds on both the technical expertise and hardware developed during the defense FEL program. The high electron beam parameter expectations are justified by a series of tests and experiments performed at Boeing and elsewhere. The two-cavity photoinjector has already been operated at 25% duty factor and 32 mA of average current in the 1990-1992 high-duty testing program [3]. These capabilities are nearly 1000 times those of any other photoinjector in time-averaged brightness. In addition, electron beam compression experiments performed in collaboration with the French FEL group at Bruyeres-le-Chatel [4] show high compression factors can be achieved and establish the need to linearize the longitudinal phase space distribution using an RF structure as part of the bunching apparatus.

Comparison with the 0.51 and 0.63 μm FEL experiments conducted at Boeing in the late 1980s shows that the expected kilowatt-level performance of the new laser is quite conservative. An extraction efficiency of 1% with strong side band generation was attained [5] with the much poorer beam quality of a thermionic injector using three stages of RF pulse compression. FELEX simulations show laser efficiencies of 3 to 4%, yielding a laser power of 2.1 to 2.8 kW (based on a 70 kW average power electron beam). Our nominal goal is 1 kW.

The existence of a 1 kW tunable FEL will stimulate the national FEL program tremendously. In addition to advancing high-power accelerator and FEL technologies, this facility will fill an empty niche in the FEL community. Presently there is no other United States FEL operating in the visible-to-near-UV wavelength range, and there is no FEL in the world with 1 kW average power. The combination of wavelength tunability and power will make possible many new and exciting industrial and medical applications; e. g., isotope separation and photo-activation of medical dyes. In particular, the affordable enrichment of a variety of isotopes with high industrial and research value can be the first commercial application of free electron lasers. Finally, the realization of a 1 kW laser will constitute a very important first step to scale the FEL to power levels required for defense applications.

B. Electron Accelerator

The electron accelerator has two separate sections: 1) an 18 MeV, high duty factor, 433 MHz pre-accelerator, and 2) seven 1300 MHz structures to complete acceleration to 120 MeV. The first section, a high average power linac [1] (Fig. 1) presently under construction, comprises a high brightness photocathode injector in two single-cell RF cavities followed by four multicell standing wave accelerator cavities. The six cavities are grouped into two separate RF systems, each energized by its own high voltage power supply, filter, crowbar/regulator, and klystron (Thomson-CSF Model TH-2120). The RF control modules (one set of which has been used successfully in the earlier test of the injector) are furnished by the Los Alamos AOT Division. These modules correct the cavity resonance frequency and stabilize the average cavity field amplitude and phase.

The 18 MeV interface between the 433 MHz pre-accelerator and the 120 MeV, 1300 MHz main linac contains an energy spectrum corrector (which we call a linearizer) and a magnetic buncher chicane that will compress the bunches from the pre-accelerator before acceleration in the main linac. A 10-cell, 1300 MHz, traveling wave structure, requiring about 1 MW RF input, will perform the dual functions of linearizing and tilting the bunch in longitudinal phase space so that it will be compressed in the chicane that follows (Fig. 1). The magnetic buncher is a three-dipole chicane with deflection angles of 30, 60, and 30 degrees; transit time variation with energy is –10 ps/%. The combination of 10-cell structure and chicane will provide beam compression factors of 4-8 to increase the peak current to 500 A and decrease the micropulse width to 7 ps for matching to the 1300 MHz high voltage accelerator [2].

The 120 MeV beam energy is reached after the bunch-compressed beam accelerates through four 1300 MHz pulsed linac modules (Fig. 1). These linac sections and the pulsed RF amplifiers which drive them utilize existing and upgraded hardware from the successful visible FEL tests performed at Boeing in the late 1980s.

The last six 1300 MHz linac sections[6] are configured in series pairs, each driven by one TH-2104/U klystron. Fabrication of these 18-cell sections is 80% complete. The first 1300 MHz linac section differs from the following six. A 25 cell section originally built as a developmental prototype for very high average beam current applications, it was used extensively in earlier visible FEL tests at Boeing. It satisfies the requirement for an additional linac section needed to reach the 120 MeV beam energy required for FEL operation at the shorter visible wavelengths.

To reach that energy with 0.1A average beam current, the linac structures require 12 MW from each of the four klystrons (rated at 15 MW peak, 250 kW average). Since the operating RF duty factor is 0.6%, the average power demanded from each of the RF systems will be only 72 kW, less than one third of the rated average power.

C. Electron Transport, Wiggler, and Resonator

After acceleration to 120 MeV, the beam is brought onto the wiggler axis by the 180^o bend (Fig. 1), which consists of four 45^o dipole and 14 quadrupole magnets arranged to make the transport doubly achromatic, with all second order geometric aberrations corrected. The bend is also nearly isochronous and is therefore excellent for preserving the short length of the bunches it transports.

Parameters for the THUNDER wiggler [7] appear in Table 1. This wiggler is unique in that its ten 50 cm sections can be individually gapped. The optical cavity [8] for the FEL will be the concentric cavity used with the THUNDER wiggler in earlier oscillator experiments. The vacuum chambers are in place on the wiggler axis, and the mirror mounts and active alignment stabilization optics are available.

II. PERFORMANCE EXPECTATIONS

Performance of the 1 kW design has been simulated using the flat pulse shape of the compressed longitudinal phase space predicted for the linac output [2]. The pulse length after compression is 7 ps with a micropulse average current of 500 A; normalized 4-times-rms emittance is expected to be 30 π-mm-mr. The combination of high peak current, an essentially flat current distribution, and low emittance allow the use of a strong, 10% energy taper in the 5 m THUNDER wiggler. Wiggler field errors and beam jitter are included. The resonator single pass mirror loss is 2.5%, primarily due to scattering. The simulation included a Littrow grating to suppress sideband growth. The FEL output power as a function of resonator outcoupling is shown in Fig. 2. At higher outcoupling the FEL does not start up due to both the high optical outcoupling and the 10% wiggler taper. An electron beam power of 70 kW (see Table 1) produces an average laser power in excess of 3 kW for outcouplings between 20% and 30%, and demonstrates that the 1 kW FEL described here is a very conservative design.

III. REFERENCES

[1] T. D. Hayward et al., "A High Duty Factor Electron Linac for FEL," paper FAA27, this conference.

[2] D. Dowell and A. Vetter, "Magnetic Pulse Compression Using a Third Harmonic RF Linearizer," paper WPR20, this conference.

[3] D. H. Dowell et al., "First Operation of a High Duty Factor Photoinjector," *Proc. IEEE Particle Accelerator Conference, Washington, D.C., 1993*, 2967.

[4] S. Joly et al., “Brightness Measurements of the ELSA Electron Beam,” contribution to the 1994 Linear Accelerator Conference, Kobe, Japan.

[5] R. L. Tokar et al., “INEX Simulations of the Boeing FEL System,” *Nuclear Instruments and Methods*, **A296**, 115 (1990).

[6] T. Buller, "Design of High Average Power Linear Electron Accelerator Sections," *Proc. IEEE Particle Accelerator Conference, Chicago, IL, 1989,* 231.

[7] K. E. Robinson et al., *IEEE J. Quantum Electron.*, **QE-23**, 1497 (1987).

[8] D. M. Shemwell et al., *Proc. 8th Int. FEL Conf, Nucl. Instr. Meth.Phys. Res.*, (1987).

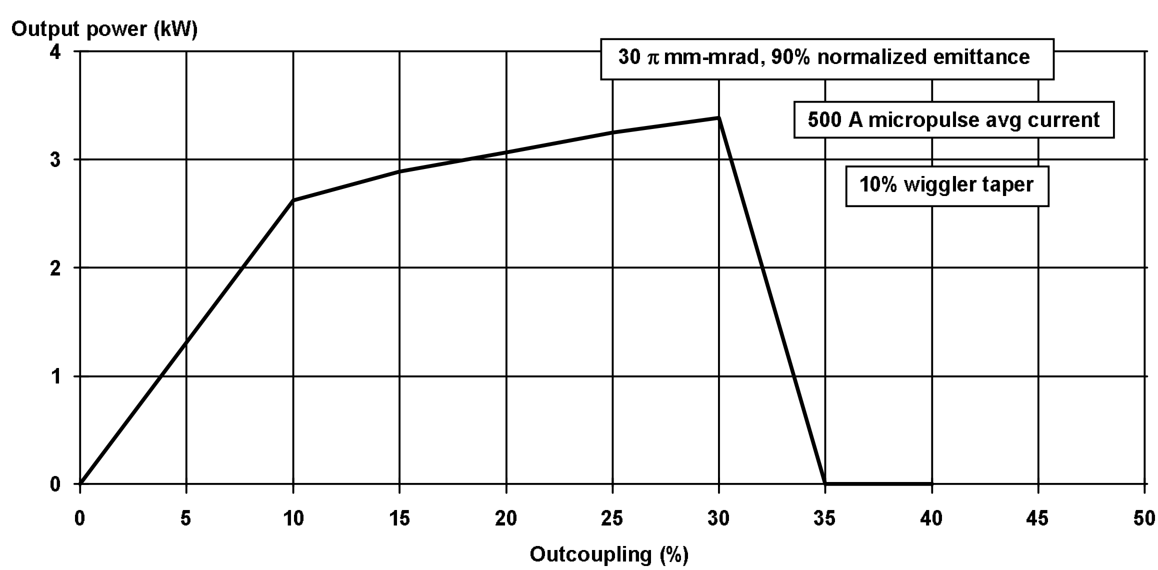

Figure 2. Output power of the proposed FEL as a function of resonator outcoupling.