THE BOEING 120 MeV RF LINAC FOR FEL RESEARCH

J. L. Adamski, W. J. Gallagher, R. C. Kennedy, B. Robinson, D. R. Shoffstall, E. L. Tyson, A. M. Vetter, and A. D. Yeremian

Boeing Aerospace Company, P.O. Box 3999, Seattle, WA 98124

Introduction

A new electron linac for high power, visible wavelength, free electron laser research is under construction at the Boeing Radiation Laboratory in Seattle. The linac is a five section, traveling wave, L band structure with a specialized "comb" pulse format of widely separated high charge micropulses.

The paper describes the accelerator design and prototyping of key components of the linac. These include a double subharmonic injector and a long pulse phase and amplitude stabilized RF source which have been tested on Boeing's 20 MeV S band linac.

Design Parameters

The definition of electron accelerator specifications for a short wavelength FEL oscillator is based on two essential requirements of the experiment:

- The single pass gain must be high to allow rapid startup.
- The experiment pulse time must be adequately long to investigate laser and accelerator instability issues.

Accelerator and laser design values are traded in a multiparameter FEL computer model developed by Quimby and Slater[1] of Spectra Technology Inc., our scientific collaborators in the FEL research. The wiggler, a hybrid steel and Samarium Cobalt permanent magnet structure, is chosen to be 5 m in length to allow electron-photon overlap with only modest electron focusing. The extraction is set at 5% (net spectral shift) consistent with our results in a 10μ FEL amplifier experiment.[2] The model calculations predict that relatively high peak current and excellent emittance will be required for a gain of 10-30% per pass. Figure 1 is a plot of single pass gain versus electron beam kinetic energy for a 5 m, 5% extraction wiggler with 0.5 μm laser wavelength. The importance of electron beam emittance, $\varepsilon_n = \beta\gamma\pi r\phi$, is obvious in the parametric curves. The experimental design point is chosen slightly high in energy to preserve as much gain as possible if the beam emittance is somewhat larger than 0.01 cm-rad.

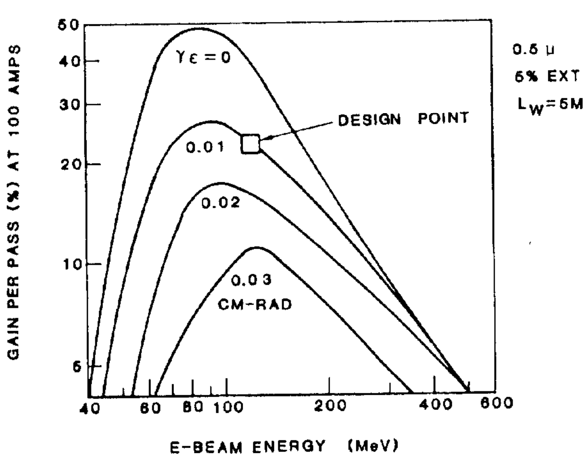

Figure 1 FEL Gain and Linac Emittance Set Beam Kinetic Energy

The RF linac current format is a series of high current micropulses spaced at the two way oscillator cavity transit time. The envelope of these pulses, the macropulse, is selected to be long enough to examine the laser startup and beam quality physics, nominally 200 μs. As a consequence of this long macropulse requirement, the susceptibility of the accelerator waveguide to beam breakup becomes a major issue.

The principal experimental parameters are given in table 1.

TABLE 1. VISIBLE FEL EXPERIMENT DESIGN

LINAC		LASER	
E	= 120 MeV	Wiggler Length	5 m
I_{peak}	= 100 A	Wiggler Period	2 cm
$\varepsilon_n=\beta\gamma\pi r\phi$	= 0.01 cm-rad	Taper	0-12%
$\Delta\gamma/\gamma$	= 0.01 Full Width	Laser Wavelength	0.5 μm
Pulse Length	= 200 μs	Startup Time (e^{20})	60 μs
		Output Power	30 kW

The Radiation Laboratory facility at Boeing is being enlarged to accommodate the accelerator and laser. The experimental configuration is shown in figure 2. The facility size is roughly 12 m x 70 m. A 55 m oscillator cavity is shown.

Accelerator Design

The 120 MeV linac comprises five accelerator sections, each powered by a 12 MW peak output RF klystron power station. The operating frequency is 1.30 GHz. The structure will be constant gradient traveling wave, operating in the 3π/4 mode. A traveling wave design has been chosen to accommodate the wide range of beam loading conditions required in the FEL experimental series. The structure has innovative features to mitigate the influence of dipole cavity modes and transverse wake fields. Synchronous interaction of the beam with transverse electromagnetic modes is minimized in 3π/4 mode structure since TM_{11}-like modes do not propagate at the velocity of light.[3] In addition, since the transverse modes have a negative group velocity, they can be removed from the structure at the upstream end of the waveguide. This is accomplished by routing the higher modes through the input RF coupler to a resistive, probe loaded coaxial pipe.

Transverse wake field effects which can degrade emittance of high charge micropulses are strongly dependent on the disk aperture diameter. A large aperture structure with acceptably low group velocity is achieved with thick disks. Shunt impedance is enhanced by contouring the disk nosecones and coving the cavities. The resultant apertures range from 5-7 cm, roughly three times the size used in our S band SLAC-like prototype accelerator.

Measurements of beam induced cavity modes have been performed for candidate structure designs. These tests, which are reported at this conference,[4] show significant transverse mode reduction in the design structure.

0018-9499/85/1000-3397$01.00© 1985 IEEE

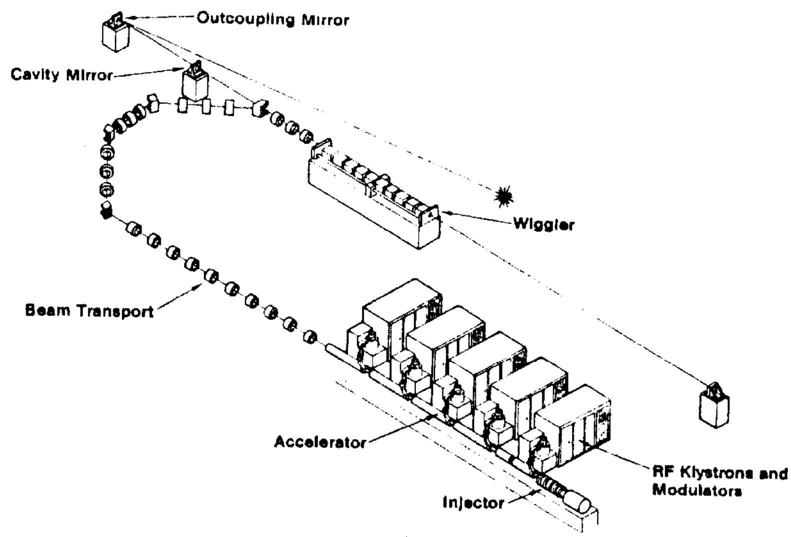

Figure 2 Visible FEL Experiment

Figure 3 is a schematic drawing of the acceleration guide. The electrical characteristics are given in table 2.

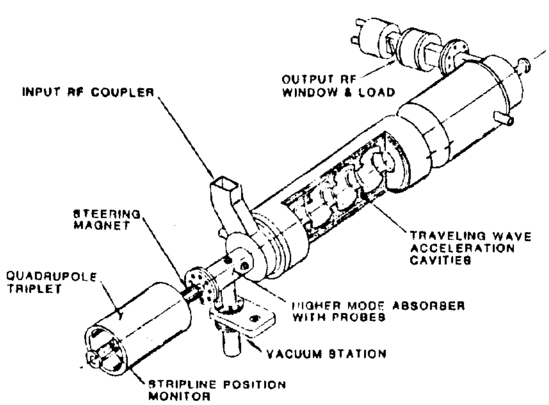

Figure 3 Acceleration Waveguide Section

TABLE 2. STRUCTURE DESIGN

Nominal Operating Freq. f	=	1300 Mcs (v_p = C)
Design Index (Attenuation) $2I_oL$	=	.6 nepers (4 dB)
Initial Attenuation Coefficient, I_o	=	.102 nepers/m
Waveguide Length, L	=	2.94 m
Shunt Impedance Per Unit Length, r	=	40 Megohms/m
Figure of Merit, Q	=	20,200
Initial Normalized Group Velocity, vg/C	=	.0067

The electric field strength at 12 MW input is 9.9 MV/m and the section no-load energy gain is 29.1 MeV. The full accelerator load line and FEL operating point are given in figure 4.

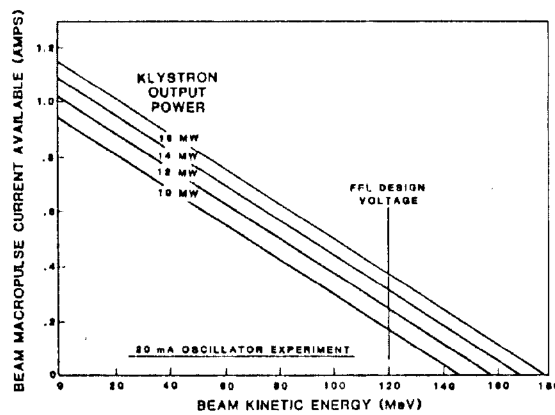

Figure 4 Accelerator Load Line

Injector

A two stage subharmonic injector for the 120 MeV linac has been designed and tested with the existing S band accelerator. Single microbunch output beam current of 120 A with emittance of 0.008 cm-rad and energy width of 1% has been measured.[5,6]

The subharmonic injector, figure 5, consists of a high current triode gun, two standing wave cavity prebunchers and a fundamental frequency tapered phase velocity buncher. A "pepper pot" emittance measurement and tuning diagnostic occupy the space between the prebuncher cavities. A full solenoidal magnetic field provides radial containment and focusing of the electron beam. A tapered collimator in the last drift section limits beam size and entry angle at the buncher.

The electron source will be similar to the SLAC-collider injector gun design. This gun provides a high brightness output and the relatively low grid drive voltage is advantageous for our requirement of high repetition, nanosecond pulse gating.

RF Power Stations

A new long pulse, phase locked RF power source is required to drive the linac. The L band klystron is under development at Thomson CSF with the design goals of 12 MW peak and 100 kW average output power in pulse widths of 200 μs.

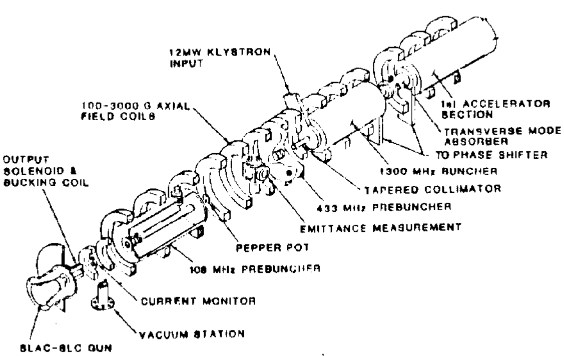

Figure 5 Two Stage Subharmonic Injector

The klystron modulator is a resonantly charged pfn pulser with thyratron output switching and de-Q regulation. A closed loop phase and amplitude regulator is used to level the output RF power to 2 degrees of phase and 0.1 dB in amplitude. A drawing of the RF power station is shown in figure 6.

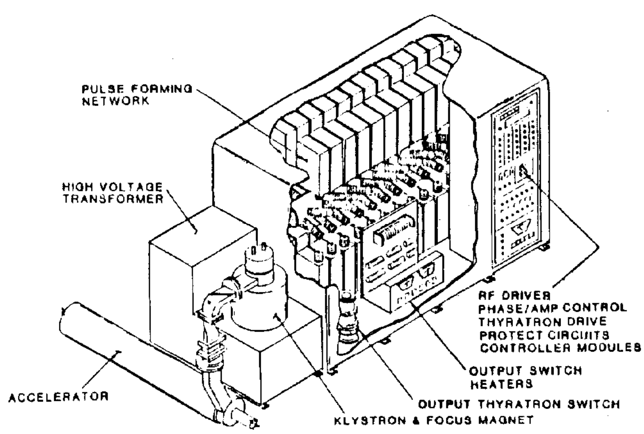

Figure 6 RF Power Station

A prototype of the power station has been built and tested on the S band accelerator. These tests verified stable operation of S band Thomson CSF klystron at 20 MW for 20 μs and 5 MW for 80 μs. The prototype phase and amplitude controller leveled the output to 2 degrees of phase and 0.2 dB amplitude with a 1 MHz control bandwidth. Testing of delay line sections showed the pfn output flatness to be within 0.1%.

Construction Schedule

The accelerator/laser facility should be ready for occupancy in the fall of 1985. Construction of the linac, the magnetic optics and the FEL will continue through spring 1986. Scheduled turn on of the laser experiment is in June 1986.

Industrial Participants

The FEL experiment is the result of the combined effort of a number of industrial firms which participated in the engineering design of critical components of the experiment. These include:

Spectra Technology Inc.	Laser design, wiggler and optical cavity fabrication
Thomson CSF	Klystron
Vectronics Microwave	Phase and amplitude control circuitry
ITT Electron Tube Div.	Switch tube development
Impulse Engineering	Switch tube drivers and fault control circuitry
Micom	Klystron drive amplifiers
Hermosa Electronics	Electron gun design
Stangenes Ind.	H.V. transformer design
TESLA	Magnetic Optics

Acknowledgment

The research leading to this paper was sponsored by Boeing Aerospace Company and DARPA/ONR under contract N00014-82-C-0548 and N00014-85-C-0039.

References

1. D. C. Quimby and J. M. Slater, Emittance Acceptance in Tapered-Wiggler Free Electron Lasers, 1983 Workshop on Free Electron Lasers, Orcas Island, WA, June 1983.

2. W. M. Grossman, T. L. Churchill, D. C. Quimby, J. M. Slater, J. L. Adamski, R. C. Kennedy, D. R. Shoffstall, Demonstration of Large Electron Beam Energy Extraction by a Tapered Wiggler FEL, 1983 Workshop on FEL, Orcas Island, WA, June 1983.

3. W. J. Gallagher, Periodic Transmission-Line Mode Measurements, Particle Accelerators, Vol. 16, p. 113, 1984.

4. A. M. Vetter, J. L. Adamski, W. J. Gallagher, Observation of Beam-Excited Dipole Mode in Traveling Wave Accelerator Structure, paper Q19, the Conference.

5. J. L. Adamski, W. J. Gallagher, R. C. Kennedy and A. D. Yereniam, A High Current Injector for the Boeing Radiation Laboratory FEL Experiment, IEEE Trans. Nuc. Sci., Vol. NS-30, No. 4, Aug. 1983, p. 2696.

6. J. L. Adamski, W. J. Gallagher, R. C. Kennedy, D. R. Shoffstall, E. L. Tyson, A. D. Yeremian, The Boeing Double Subharmonic Electron Injector - Performance Measurements, paper D43, the Conference.