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Inverse Free-Electron Laser Accelerator Development

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Inverse Free-Electron Laser Accelerator Development*

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Abstract

We present a design of a short accelerator module making use of the Accelerator Test Facility, high brightness, 50 MeV linac and its high power CO_2 laser.

The study of the INVERSE FREE ELECTRON LASER, as a potential mode of electron acceleration, has been pursued at Brookhaven National Laboratory for a number of years. More recent studies focused on the development of a low energy (few GeV), high gradient, multistage linear accelerator.[1] We are presently designing a short accelerator module , which will make use of the 50 MeV linac beam and high power (2×10^{11} W) CO_2 laser beam of the Accelerator Test Facility (ATF) at the Center for Accelerator Physics (CAP), Brookhaven National Laboratory. These elements will be used in conjunction with a fast excitation (300 μsec pulse duration) variable period wiggler, to carry out an accelerator demonstration stage experiment.

The wiggler makes use of alternating stacks of Vanadium Permandur (VaP) ferromagnetic laminations, periodically interspersed with conductive, nonmagnetic laminations, which act as eddy current induced "field reflectors."[2] A typical period length taper for the IFEL experiment is $\lambda = 3.0 - 5.0$ cm, $\frac{d\lambda}{dz} \approx 4\%$. Maximum field enhancement of approximately a factor of 2 is obtained with the use of the field reflectors.[3] Other wiggler parameters are: gap= 4 mm; $B_{max} \approx 14\,kG$ (I = 6 kA) and maximum field variation pole-to-pole, $\sigma(\Delta B/B) \approx 0.2\%$. The wiggler configuration is illustrated in Fig. 1. The CO_2 laser beam will be transported through the IFEL interaction region

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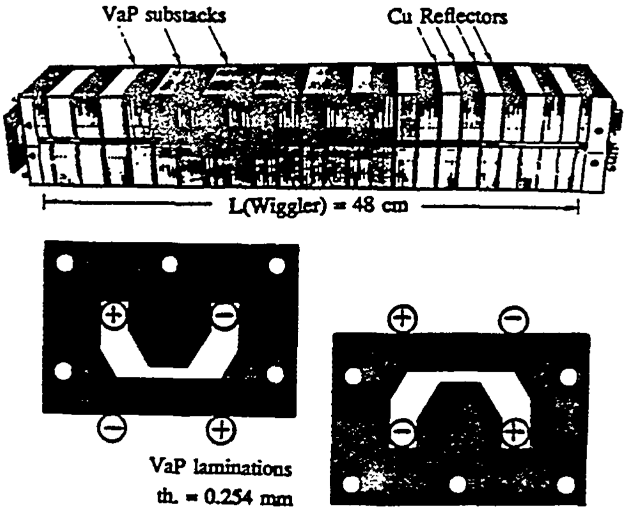

Figure 1: Variable period wiggler consistent of stackable, interleaved VaP laminations and Cu eddy current 'field reflectors'

by means of a low loss dielectric coated metallic rectangular waveguide or a dielectric circular waveguide. Waveguide test sections have been constructed and have been tested using a low power cw CO_2 laser ($\lambda = 10.6\,\mu m$). The results are indicated in Fig. 2. For a 1 m long, 2.8 mm i.d., circular dielectric, single crystal extruded Al_2O_3 (sapphire) guide, an attenuation coefficient α [defined by $\frac{P(z)}{P_o} = \exp(-2\alpha z)$] of 0.18 dB/m has been measured. In parallel with the low loss guide experimental program, 2D diffraction type calculations are in progress, preliminary results of which support the feasibility of coupling efficiently the laser Gaussian beam into the desired low loss guide mode, in a coupling guide length of ≈ 0.5 m. The IFEL design is supported by the development and use of 1D and 3D simulation programs. The 1D program has been used to define an optimal tapered wiggler for given values of laser power P, synchronous phase Ψ and wiggler magnetic field B_{max}; and has been used to calculate bucket acceptance and bucket leakage of a single or multistage accelerator for a number of laser power, guide losses, wiggler errors and electron beam energy spread and emittance cases. The 3D code has been used to study beam walk-off, displacement and steering; and transverse phase space and emittance growth. An example of the IFEL simulation is given in Fig. 3. An experimental test of IFEL electron beam acceleration is scheduled to be carried out at the BNL ATF during the latter part of the year 1994. Initially, this will be done with a CO_2 laser power of 5×10^9 W, limiting the energy gain of the electron beam (45 MeV) to 2.5 MeV. Subsequently, making use of a power upgraded CO_2 laser, enhanced electron beam energy gain should be achievable, as indicated in Table I.

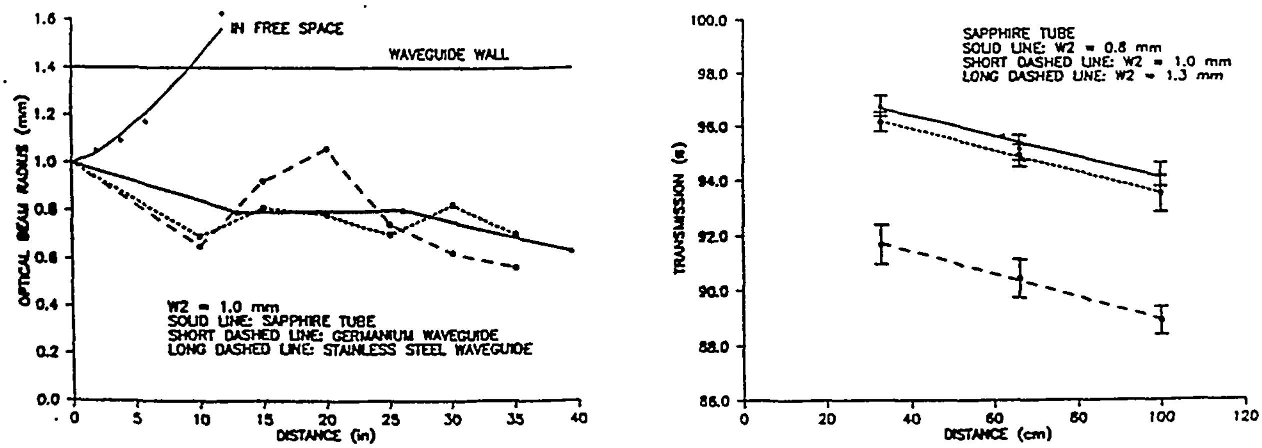

Figure 2: Waveguide transmission of CO_2 laser beam with a waist at the entrance of $\omega_o = 1$ mm. a) Radius, b)Transmission as a function of the length of the waveguide

Table 1. Parameters for an IFEL experiment at the Accelerator Test Facility

Electron Beam		
	Injection energy	48.9 MeV
	Exit energy	87.95 MeV
	Mean accelerating field	89 MV/m
	Current, nominal	5 mA
	N (bunch)	6×10^9 e$^-$
	I (max)	100 A
	$\Delta E/E$ (1 σ)	$\pm 3 \times 10^{-3}$
	Emittance (1 σ)	7×10^{-8} m-rad
	Beam radius	0.3 mm
Wiggler Parameters		
	Wiggler length	0.47 m
	Section length	0.6 m
	Period length	2.86-4.32 cm
	Gap	4 mm
	Field (constant B mode)	1.25 T
	Horiz. max. amplitude	0.17-0.22 mm
Laser parameters		
	Power	2×10^{11} W
	Wavelength, λ	10.2 μm
	Max. Field	1.36×10^4 MV/m
	Guide loss par. α	0.025 m^{-1}
	Field attenuation/section	0.13 dB
	Pulse length (FWHM)	6 ps

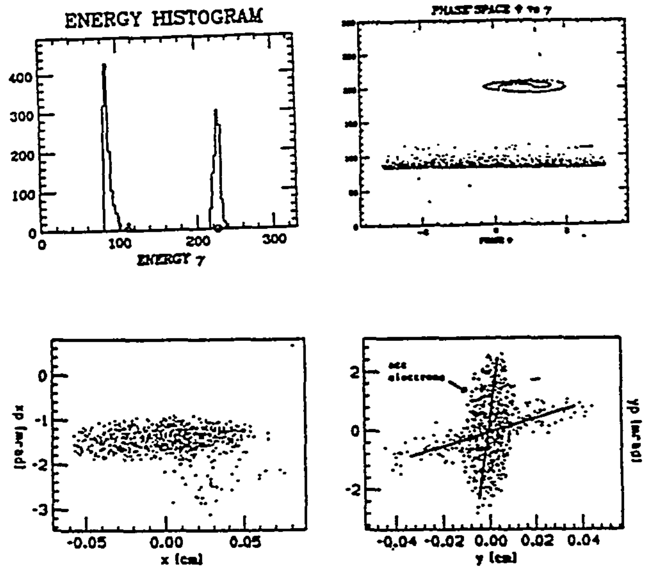

Figure 3: 3-D simulation results; first figure (clockwise, starting from the top-left) shows the number of accelerated and non-accelerated particles; next figure is the $\gamma - \Psi$ phase space; following is the vertical transverse phase space (y - y′) and the last one is (x - x′)

The experimental arrangement to be used is shown in Fig. 4.

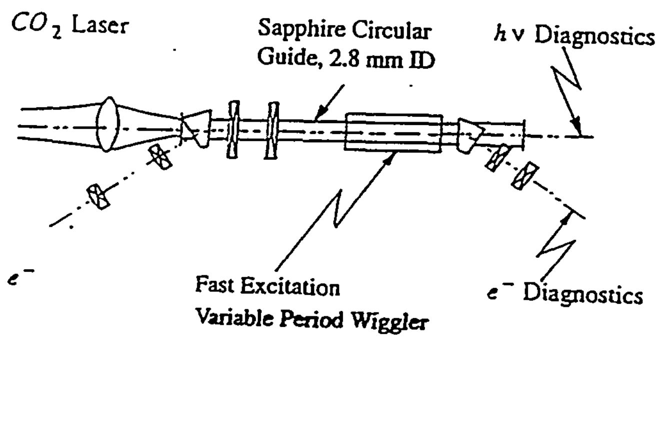

Figure 4: Experimental setup of an IFEL experiment at the Accelerator Test Facility

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