THE UCLA HELICAL PERMANENT-MAGNET INVERSE FREE ELECTRON LASER*

R. Tikhoplav#, J. Frederico, G. Reed, J. Rosenzweig, S. Tochitsky, G. Travish UCLA, Los Angeles, CA 90095
G. Gatti INFN/LNF, 00044 Frascati (RM) Italy

Abstract

The Inverse Free Electron Laser (IFEL) is capable, in principle, of reaching accelerating gradients of up to 1 GV/m making it a prospective accelerator scheme for linear colliders. The Neptune IFEL at UCLA utilizes a 15 MeV Photoinjector-generated electron beam of 0.5 nC and a CO_2 laser with peak energy of up to 100 J, and will be able to accelerate electrons to 100 MeV over an 80 cm long, novel helical permanent-magnet undulator. Past IFELs have been limited in their average accelerating gradient due to the Gouy phase shift caused by tight focusing of the drive laser. Here, laser guiding is implemented via an innovative Open Iris-Loaded Waveguide Structure (OILS) scheme which ensures that the laser mode size and wave front are conserved through the undulator. The results of the first phase of the experiment are discussed in this paper, including the design and construction of a short micro-bunching undulator, testing of the OILS waveguide, as well as the results of corresponding simulations.

INTRODUCTION

New alternative acceleration schemes have been actively studied in recent years. One of them is the Inverse Free Electron Laser (IFEL) which allows energy transformation from a laser to the electron bunch propagating through a magnetic undulator with a matching period. A high-gain IFEL experiment has been successfully conducted at the UCLA Neptune facility [1]. That experiment used an undulator with a planer symmetry. In this paper we suggest using a helical undulator which employs a cylindrically symmetric geometry. Such geometry is interesting because it provides a better coupling to cylindrically symmetric electron beam and it also allows a bigger gap which makes aligning of a laser and an electron beams much easier.

EXPERIMANTAL SET-UP

The Neptune facility at UCLA consists of a 15 MeV Photoinjector linac which can provide a charge of up to 0.5 nC and a CO_2 laser with peak energy of up to 100 J. The IFEL utilizes a helical permanent-magnet undulator of Halbach geometry. To provide the guiding of 10.4 micron CO_2 laser beam through the udulator, we propose to use an open iris-loaded structure (OILS) waveguide.

*Work supported by US Department of Energy
#rodion@ucla.edu

We will first build a short (10 cm) undulator and a waveguide to test the coupling by observing a micro-bunching. Then, as a second step, we will build a long waveguide and a tapered undulator (80 cm).

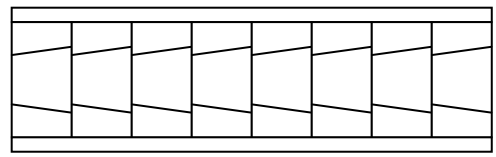

Figure 1: OILS Waveguide.

OILS Waveguide

A scheme for propagating a laser beam in an open iris structure has been analyzed in detail by M. Xie [2]. Such a scheme is analogous to propagation in a Fabry-Perot resonator with flat mirrors and it has not as yet been tested for the fundamental laser mode [3].

An important advantage of an OILS waveguide is its over-sized dimension compared to the laser wavelength. The structure consists of a number of stacked elements with a circular opening of radius *a* (see Fig. 1).

Each element has tapered edges with the angle of tapering greater than the diffraction divergence angle $\theta_d \approx \lambda/a$ so that the light sees it as an infinitely thin iris. The parameters of such a structure are given in Table 1.

Table 1: Laser and Waveguide Parameters

Parameter	**Value**
Total Length	80 cm (10 cm)
Diameter, $2a$	2.26 mm
Number of Elements	267 (33)
Thickness of an Element, L	3 mm
Wavelength, λ	10.6 um
Waist, w_0	0.7 mm
Laser Pulse Length	100 ps
Laser Pulse Energy	8 J
Laser Intensity, I	500 GW/cm^2
Peak Electric Field, E_0	1.94 GV/m

The structure can be visualized as an "unfolded" flat mirror Fabry-Perot resonator with Fresnel number:

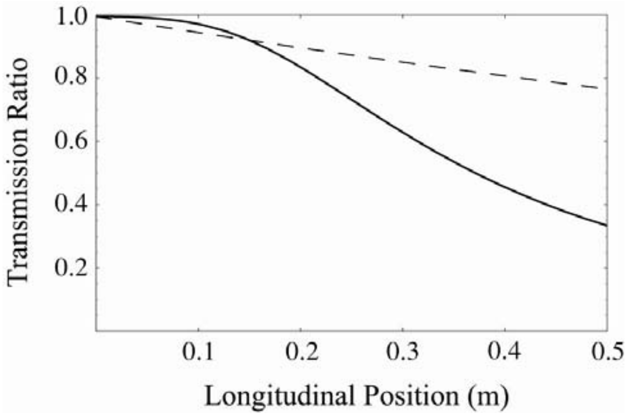

Figure 2: Genesis simulation of transmission of a Gaussian beam through OILS (dashed) and through an aperture in free space (solid).

$$N = a^2 / \lambda L = 40 \quad (1)$$

and quality factor:

$$Q = 2\pi L / \lambda \alpha_c = 1.7 \times 10^6 \quad (2)$$

where $\alpha_c = 8\nu_{01}^2 (M+\eta)\eta / [(M+\eta)^2 + \eta^2]^2$ is the loss per cell, and $\nu_{01} \approx 2.405$ is the first zero of Bessel function $J_0(\nu_{01}) = 0$, $\eta = -\varsigma(0.5)/\pi^{1/2} = 0.824$ and ς is Riemann's Zeta function; $M = [8\pi N]^{1/2}$. Theoretical losses over a length of 50 cm should be less than 25% [4], see Fig. 2. A 10 cm prototype has been successfully built and tested. 90% transmission has been achieved.

Undulator

To couple an electron and laser beams the electrons need to pass through a periodic magnetic field. To create such field we will use an array of magnets called an undulator. The laser wavelength, λ and undulator parameters are related as follows:

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + K_u^2\right) \quad (3)$$

where λ_u is undulator period, γ is the Lorentz factor of electrons and $K_u = eB_u \lambda_u / 2\pi m_e c$ is the undulator constant, where B_u is the magnetic field in undulator, c is velocity of light, e and m_e are electron charge and mass respectively.

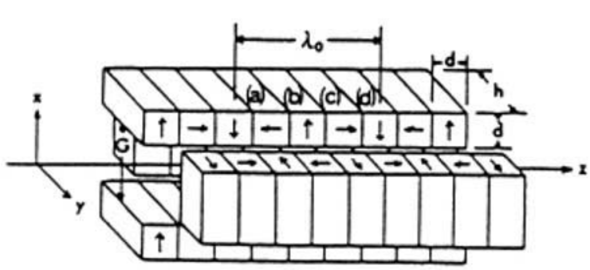

Figure 3: Undulator schematics. Arrows indicate the direction of magnetic field.

Table 2: Undulator and Electron Beam Parameters

Parameter	**Value**
Undulator Length	10 cm
Undulator Gap	13 mm
Undulator Constant, K_u	0.094
Field Amplitude , B	0.069 T
Undulator Period, λ_u	14.6 mm
Electron Energy	13.5 MeV
Electron Charge	0.1 nC
Normalized Emmitance	5 mm-mrad
Electron Beam rms Size	0.3 mm

We will use a Halbach type helical permanent magnet undulator. There are four magnets per period and there are four segments in transverse dimension as well, see Fig. 3. Each magnet piece is 11 mm by 11 mm by 4 mm magnetized to 1 T field. Each piece is imbedded into aluminum holder which can slide in radial direction to provide fine tuning. See Table 2 for the undulator and electron beam parameters.

The undulator and the OILS waveguide will be put into the vacuum box in the Neptune beamline, where it will be aligned with the CO_2 laser.

Coherent transition and Cherenkov radiation techniques will be used as a microbunching diagnostic tool.

SIMULATION RESULTS

A 3D magnetostatic code Radia [5] is used to simulate magnetic field map in the undulator, see Fig. 4. Radia constructs three dimensional objects with corresponding material properties and then solves the magnetization problem employing a Boundary Integral Method.

Genesis 1.3 [6] was used to model propagation of electron beam through undulator and its interaction with guided laser bean. Genesis is a time-independent electro-

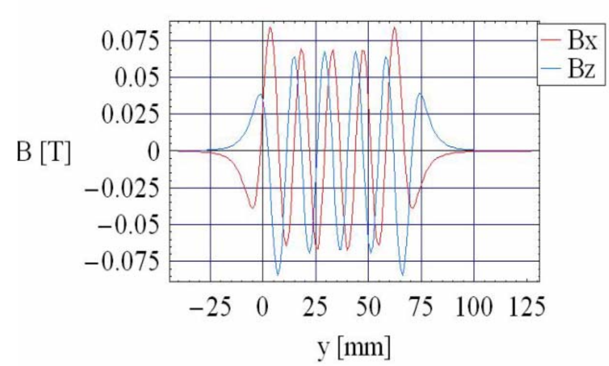

Figure 4: Simulation of the magnetic field in undulator.

1-4244-0917-9/07/$25.00

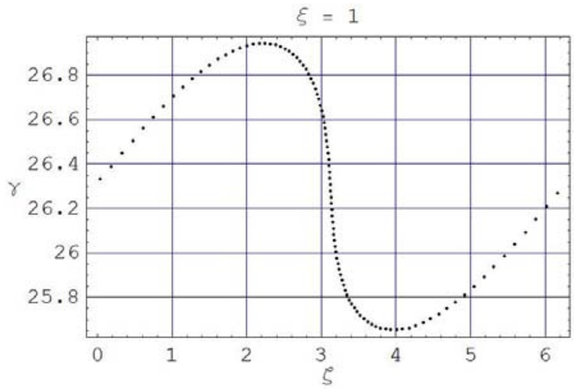

Figure 5: Genesis simulation of the energy-phase modulation after 30 cm drift.

magnetic propagator which tracks electron beam of a given shape including a space-charge effect. A 30 cm drift section was introduced into simulation to translate an energy modulation in the undulator into microbunching (see Fig. 5) which can be measured using the techniques described above.

SUMMARY

A novel helical undulator and OILS waveguide are being developed and will be implemented at Neptune facility at UCLA. The first stage consists of a bunching experiment using a short (10 cm) undulator. Then, as the second stage, a full scale 80 cm undulator will be built with 100 MeV/m acceleration gradient expected.

REFERENCES

[1] P. Musumeci, *et al.*, *Phys Rev. Lett*. **94**, 154801 (2005).
[2] M. Xie, Proc. of 1997 Part. Accel. Conf. 660 (1997).
[3] R. Tikhoplav, *et al.*, Proc. of 2002 Europ. Part. Accel. Conf. 984 (2002).
[4] J. Frederico, *et al.*, these proceedings.
[5] www.esrf.eu/Accelerators/Groups/InsertionDevices/Software/Radia/
[6] pbpl.physics.ucla.edu/~rieche/