STATUS OF UCLA HELICAL PERMANENT-MAGNET UNDULATOR

A. Knyazik, R. Tikhoplav, J. B. Rosenzweig, Department of Physics & Astronomy, UCLA, Los Angeles, California 90095, U.S.A.

Abstract

A helical undulator, utilizing permanent-magnet of cylindrically symmetric (Halbach) geometry has been developed at UCLA's Neptune Facility. The initial prototype is a short 8.8 cm, 6 periods long helical undulator, designed to test the electron-photon coupling by observing the micro-bunching has been constructed and is currently being tested in the Neptune facility. Coherent Transition Radiation and Coherent Cherenkov Radiation are used for micro-bunching diagnostic. Currently the undulator has been built; magnets were calibrated using magnetic field probe and via pulsed wire method.

INTRODUCTION AND SETUP

An Inverse Free Electron Laser (IFEL) is an alternative acceleration scheme that lets a laser transfer energy through use of a magnetic undulator to an electron bunch. Previously high-gain IFEL experiments have been successful at UCLA's Neptune facility [1], which utilizes a 100 J CO2 laser and a 15 MeV 0.5 nC Photoinjector linac. All previous undulators used at Neptune had planar symmetry. Using cylindrically symmetric undulator provides better coupling to an electron beam. It also allows separation between adjacent magnets to be bigger, which makes electron propagation through undulator easier. To test cylindrically symmetric undulator IFEL experiment in Neptune we're building an 8.8 cm, 6 periods long, helical permanent-magnet undulator of Halbach geometry [2]. 10.6 µm CO2 laser light is propagated through the undulator to produce electron micro-bunching.

Undulator

A structure which has an array of magnets of alternating direction is called an undulator. Period of an undulator can be related to the laser wavelength (see Eq. 1 and Eq. 2).

$$\lambda = \frac{\lambda_u}{2\gamma^2}(1 + K_u{}^2) \qquad (1)$$

Where K_u is the undulator constant,

$$K_u = \frac{eB\lambda_u}{2\pi m_e c} \qquad (2)$$

γ is energy of the electron beam, λ_u is the undulator period, and B is the magnetic field, me is electron mass, c is speed of light, e is electron charge, and λ is the laser light wavelength. Undulator parameters are given below in Table 1.

Table 1: Undulator, Electron Beam, and Laser Parameters.

Parameter	Value
Undulator Length	8.8 cm
Undulator Gap	13 mm
Undulator Constant, K_u	0.1
Magnetic Field, B	0.075 T
Undulator Period, λ_u	14.6 mm
Electron Energy	12.75 MeV
Electron Charge	0.1 nC
Normal Emittance	4 mm-mrad
Electron Beam rms size	0.3 mm
Wavelength, λ	10.6 µm
Waist, w_0	0.7 mm
Laser Pulse Energy	0.38 J
Laser Intensity, I	170GW/cm^2
Peak Electric Field, E0	1.94 GV/m

The UCLA Halbach helical permanent magnet undulator [3], has four magnet segments per undulator period, and four magnets per one quarter period (see Figure 1). Each magnet has magnetization of 1.22 T (see Figure 2).

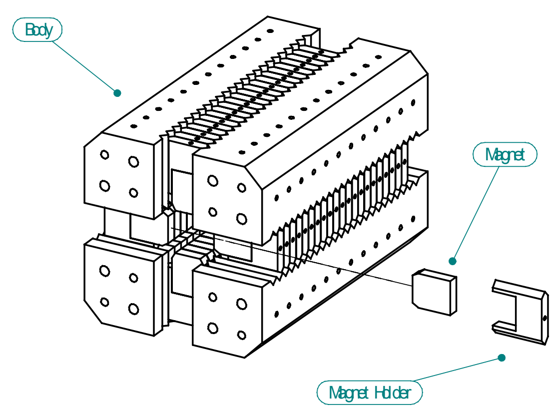

Figure 1: Undulator body and magnetic dipoles glued into their holders can slide back and forth to adjust the magnetic field B.

Figure 2: A completed dipole glued into its holder. Altogether there are 6 periods so 84 magnets in the undulator; 21 magnets magnetized in same direction, with 4 directions of magnetization as shown in Figure 1.

SIMULATION AND MEASUREMENTS

Magnetic fields in the undulator were calculated using a Mathematica add-on called Radia [4]. Using a magnetic probe mounted on a computer motorized 1-D translation stage we mapped the magnetic field inside the undulator, from which we can calculate the velocity and trajectory of electrons as they propagate through the undulator, and compare them with Radia simulation results. Below is a graph of horizontally oriented magnetic field (x-direction) is plotted versus the undulator central axis (y-direction) (see Figure 3).

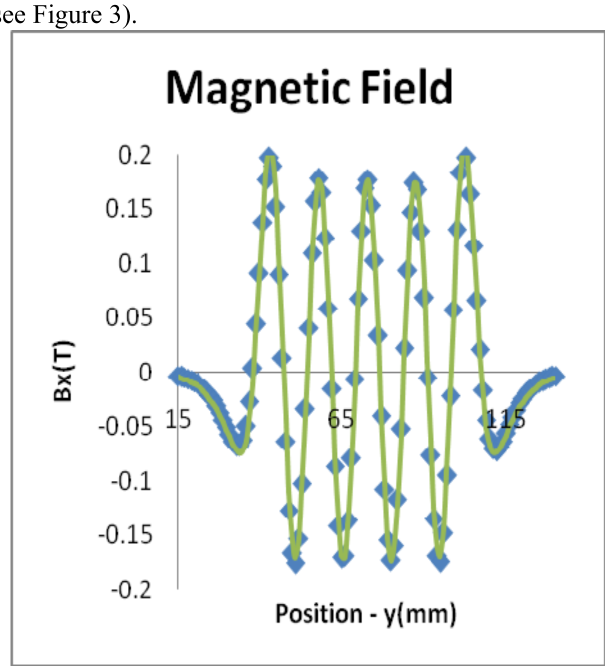

Figure 3: Comparison of magnetic field in simulation and measurement: Radia simulation is graphed in solid line, and magnetic probe measurement in the middle of the undulator is graphed in blue rhombuses.

Due to similarity of measurement and simulation of the magnetic fields, the trajectory and velocity of electrons are same when we compare Radia simulation to calculation from magnetic probe data, the next two graphs are just of the Radia simulation of the velocity and offset of the electrons as the propagate through the undulator (see Figure 4). First graph depicts the velocity of electrons in x-direction (relative to speed of light) versus y-axis. Second graph depicts the trajectory of electrons in x-direction versus the y-axis. Note: The magnitude of magnetic field is greater then what is needed for our K value, however the magnetic field can be easily decreased by pulled magnets back by 1.2 mm.

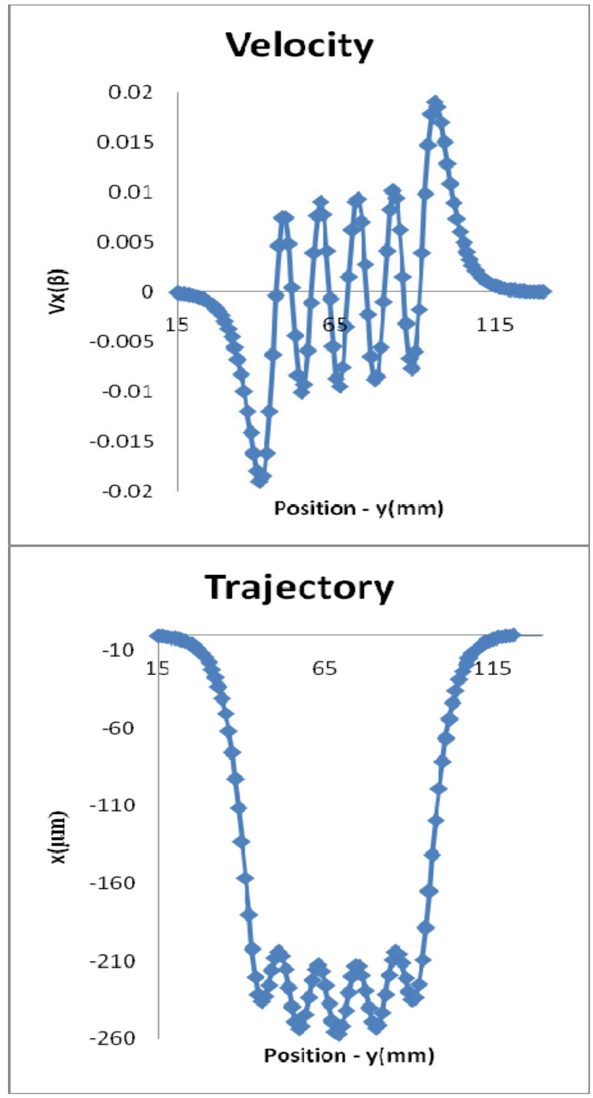

Figure 4: Velocity and trajectory of electrons passing through undulator as predicted by Radia simulation.

Fine tuning of the undulator to ensure a proper trajectory will be done using pulse wire method [5]. A phononic wave is excited on a wire that is placed through parallel axis of our undulator, by generating a short electric pulse. Depending on the pulse length pulse wire method can tell us two useful properties: a short pulse will show the peaks and troughs of a magnetic field while a long pulse, that covers the whole undulator length will show us the trajectory of electrons. Pulse wire method yields us the same results for both magnetic field and trajectory as does the magnetic probe measurements.

CURRENT STATUS

Design, computer simulation, and manufacturing of parts for the helical undulator have all been completed (see Figure 5). All magnets were constructed and glued into their holders, whose tolerances turned out to be much better than we expected yielding in a magnet's position deviating from the center by up to 150 µm. Through computer simulation, we calculated how to shift the magnets to take care of these magnet position errors without compromising the electron trajectory through the undulator. Currently we have aligned the magnet's position using magnetic probe, and verified using pulsed wire method. This undulator is a first stage of an acceleration scheme, which will pre-bunch the electron beam. Upon completion, and successful micro-bunching, a second-stage 80 cm helical undulator will be built, expected of having 100 MeV/m acceleration gradient.

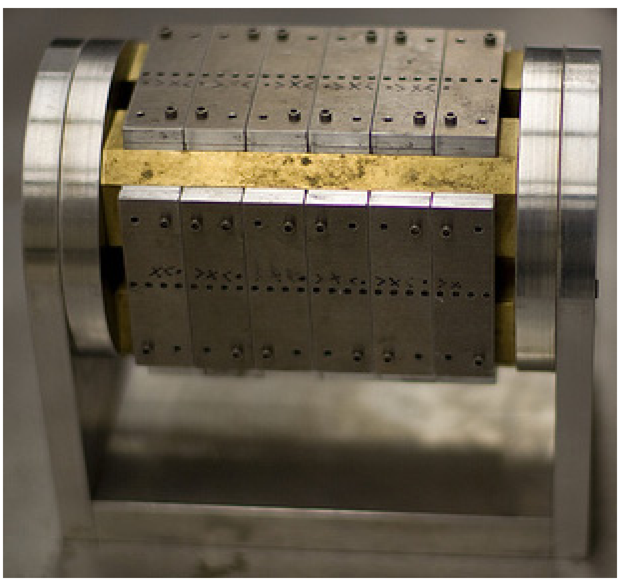

Figure 5: Manufactured undulator with all dipoles inserted.

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