DESIGN OF A REVOLVING HELICAL STAGGERED UNDULATOR

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Abstract

This investigation proposes a revolving helical staggered undulator with 10-mm and 15-mm period lengths for free electron laser operation. The helical staggered structure with a 10-mm period length is designed to produce vertical and horizontal field strength of 0.625 T at a phase shift of 90 degrees, by driving a longitudinal solenoid field of 0.7 T with a 3-mm gap. Three-dimensional magnetic field analysis was performed using RADIA computer code. An optimized magnetic structure was studied over various operating field ranges. A revolving helical undulator is equipped with two helical magnetic arrays to switch the helicity of radiation and broad radiation spectrum. Accordingly, the design of a helical staggered undulator is outlined.

INTRODUCTION

Several insertion devices can generate circular polarized light, including the APPLE II type undulator and the crossed undulator. In a planar undulator, the APPLE II provides the highest circular polarization rate, which depends on the gap and the phase position [1]. Hence, an APPLE II undulator has been used in the storage ring at various laboratories. However, for free electron laser (FEL) operation, the undulator must satisfy strict mechanical tolerances and magnetic field quality requirements. In most cases, the undulator is constructed with a fixed gap to prevent the severe complications associated with gap movement and phase shift.

A shorter period undulator with higher fields can extend the spectral range. For FEL applications, a shorter periodic length corresponds to a smaller overall undulator length. Typically, an aperture needs only to be large enough for single-pass beams. It made possible to lead a helical undulator with a small gap width. In addition, a helical undulator always generates a higher magnetic field than a planar undulator. Hence, a helical staggered undulator, which can be operated simply and stably, is being developed at the National Synchrotron Radiation Research Center (NSRRC) in Taiwan.

In this work, a helical staggered undulator with a 10-mm period length is designed to create strong vertical and horizontal magnetic fields. In principle, the magnetic field strengths must be equal, and the phases of the magnetic fields must be 90^{o} apart to produce circularly polarized light. The helical staggered undulator is comprised of two planar staggered arrays shifted by a quarter of a period length parallel to the longitudinal axis to generate *By* sin2πz and *Bx* cos2πz magnetic fields along the longitudinal z axis [2]. Figure 1 presents the proposed helical undulator design. Table 1 lists the main parameters.

Table 1: Main parameters of helical staggered undulator

Undulator type	Helical/Revolving		
Period length	mm	10	15
Fixed gap width	mm	3	3
K value		0.8	1.58
Peak on-axis field	T	0.86	1.13
Horizontal field strength	T	0.62	0.8
Vertical field strength	T	0.62	0.8
Polarization mode		circular	circular

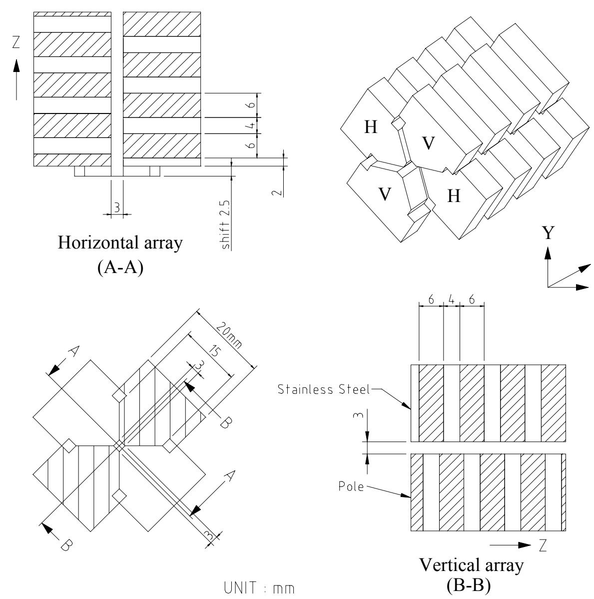

Fig. 1 Schematic view of the helical staggered array

MAGNETIC DESIGN

In designing an undulator for a given energy, the

$$E_f[eV] = \frac{950\ E_e^2[GeV]}{\lambda_u (1 + K^2/2 + \theta^2\gamma^2)}$$

wavelength of the emitted radiation is given by

Where *K*=0.934 B (T) λu (cm),

$$B = \sqrt{B_x^2 + B_y^2}$$

For circular polarized light, *Bx*=*By*, Note that a helical magnetic field has $\sqrt{2}$ times the peak magnetic field strength of the identical horizontal and vertical field as compare to a planar undulator. The periodic magnetic circuit must be optimized by a reasonable gap to maximize the magnetic field strength. Wake field effects

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and magnet radiation damage determine the gap limit on the vacuum chamber aperture and the undulator gap [3]. An undulator must be used in vacuum to widen the aperture as much as possible. The permanent magnet is not employed in the staggered undulator without concerning the magnet degradation in the small gap. Accordingly, the helical staggered undulator enables the horizontal and vertical gaps to be as narrow as possible.

The original planar "staggered-array wiggler" was built at Stanford University [4]. A staggered-array undulator consists of a superconducting solenoid coil and two rows of vanadium permendure pole stacks and stainless steel half-blocks. The solenoid field is deflected vertically into each vanadium permendure face, to generate an alternating vertical field. Two planar staggered undulators, shifted a quarter of a periodic length, are separated by a fixed gap width to generate a helical field. In the helical undulator, the pole region is completely symmetrical at a declination angle of 45^{o} to the axis, increasing the available space in both the vertical and the horizontal directions.

Figure 1 presents the configuration of the magnetic structure with 10-mm period length. The alternating sinusoidal field is derived from the helical staggered magnetic array by changing the current in the superconducting solenoid coil. The pole blocks are constructed from vanadium permendur. Magnetic field calculations have been made using RADIA 3D computer code [5]. Three-dimensional field analysis optimized the periodic magnet structure. Figure 2 plots the variation of the peak fields as a function of the magnetic gap at a current density of 30 A/mm^2.

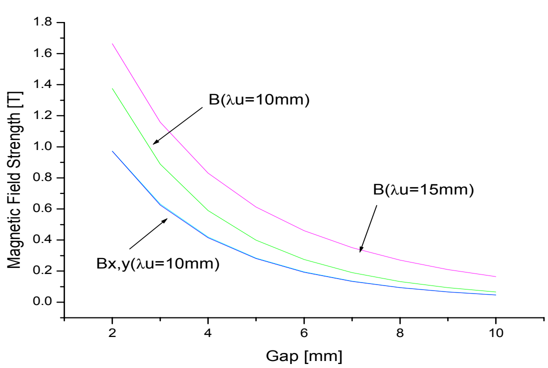

Fig. 2 The variation of the peak fields as a function of the magnetic gap at a current density of 30 A/mm^2.

The horizontal staggered magnetic array was in the quarter-period shift position. The 3-mm wide sharp pole must accommodate a minimum magnetic gap width. The width of the pole is chosen to yield the strongest magnetic field in the mid-plane. Varying the current density between 0 and 50 A/mm^2 yields a maximum field of 0.625 T due to saturation of the vanadium permendur pole. A peak vertical and horizontal magnetic field of 0.625 T was achieved by driving a longitudinal solenoid field of 0.7 T in a 3-mm wide gap. Figure 3 presents the horizontal and vertical fields in one period length, derived from solenoid field with vanadium permendur pole.

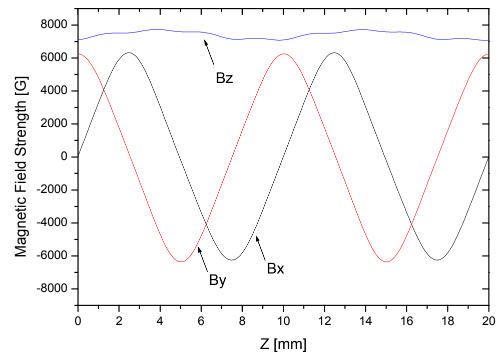

Fig. 3 The horizontal and vertical fields in a 10-mm period length, derived from solenoid field

The region of uniform field is also sensitive to the width of the narrow gap. The small width of pole is constrained by the width of gap. Therefore, the homogenous field is constrained in a narrow region around the beam axis. The magnetic field is less uniform nearer the axis because the ferromagnetic pole pieces from the conjunctive magnetic array. The integrated multipole errors are not very critical in an electron single pass undulator. Figure 4 plots the vertical field distributions along the horizontal axis at y=0 mm and the vertical axis at x=0 mm.

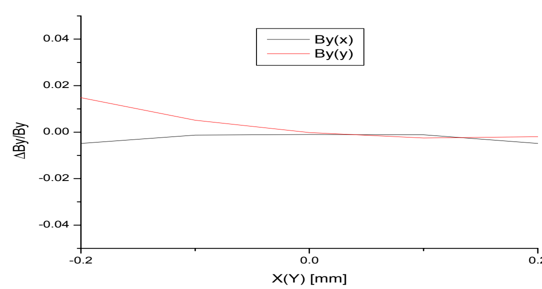

Fig. 4 The vertical field distributions along the horizontal axis at y=0 mm and the vertical axis at x=0 mm.

An anti-symmetric magnetic array configuration was designed under stringent magnetic field requirements to increase the effective magnetic pole. The end pole field is analyzed using three-dimensional calculations. The magnetic pole is magnetically saturated, and the helical fields are thereafter insensitive to the strong longitudinal field strength. The trim coils in the end coil region can be partially adjusted to compensate for the homogeneity of the helical field at both ends. The effective poles were optimized to reduce the vertical and horizontal fields integral using various solenoid currents. Figure 5 plots the calculated vertical, horizontal and longitudinal field distributions in a helical staggered with 10-mm period length undulator.

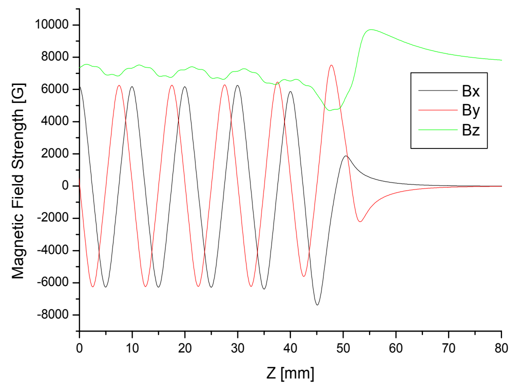

Fig. 5 The calculated vertical, horizontal and longitudinal field distributions at the end pole region.

REVOLVING HELICAL STAGGERED ARRAYS

The phase of two planar staggered arrays must be longitudinally movable to reverse the helicity of radiation. However, the phase shift of magnetic arrays in vacuo requires a complicated mechanical design and may be disrupt the electron beam in FEL. The challenging requirement on the magnetic and mechanical designs is to maintain the overlap between the electron beam and the photon beam over the entire length of the undulator. In this study, the revolving undulator with multi-staggered arrays in a single device is proposed. Figure 6 outlines the proposed configuration. One magnetic array creates left circularly polarized light and another creates right circularly polarized light. The back-beam may be interchanged. Right or left circularly polarized light can be selected by rotating the cylindrical strongback frame. The electron beams pass through an offset center so a single device is used to generate both right and left circularly polarized light.

Ordinarily, the high magnetic field is limited in the short period undulator. Accordingly, the short period undulator generates a narrow or discontinuous photon spectrum between the high harmonics. Here, several period lengths can be served with a single device for compensating the discrete photon spectrum. Such multi-magnetic arrays provide various periodic lengths to broaden the photon spectrum. A cylindrical diameter of 200 mm can support four different magnetic structures as indicated in Fig. 6.

The helical staggered undulator, with perfectly identical horizontal and vertical fields generates ideally circularly polarized radiation at the fundamental harmonic. Circularly polarized spectra can be generated using a helical undulator with 10-mm and 15-mm period lengths at fundamental harmonics. The photon energy from a 50 MeV linear accelerator is produced in the 0.7-2.4 eV range.

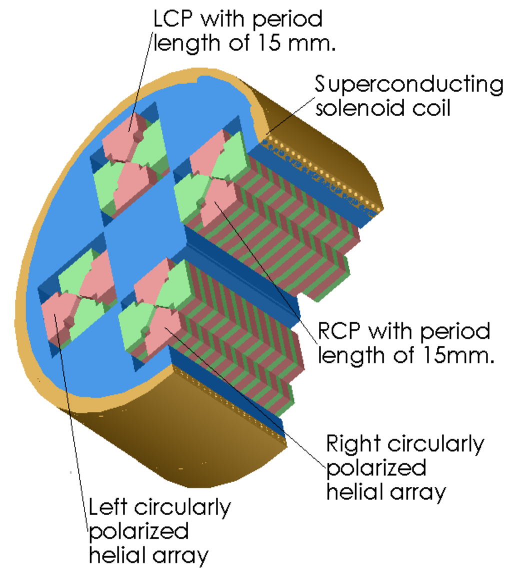

Fig. 6 The configuration of revolving multi-magnetic arrays.

CONCLUSIONS

Decreasing the periodic length of the helical staggered undulator significantly increases the number of periods. This device with 10-mm period length generates both sinusoidal and helical on-axis magnetic fields of 0.625 T in a gap width of 3 mm. Such an undulator can produce perfectly circularly polarized radiation whose direction of circular polarization can be changed by multi-magnetic arrays on a single support. Moreover, the multi-magnetic arrays concept is applied to broaden the photon energy. This proposed revolving helical undulator provides the advantages of ease of fabrication and low cost in a particular gap width. The helical staggered undulator is mostly effective undulator in terms of mechanical tolerance, magnetic field error and cost.

REFERENCES

[1] S. Sasaki, Nucl. Inctru. And Meth., A347(1994), 83.
[2] J. Pfluger, “Undulator for SASE FELs”, Nucl. Instr. and Meth., A445, 366-372 (2000)
[3] H. Onuki, Nucl. Instru. Methods, A246, p94 (1986)
[4] Y. C. Huang, etc., Nucl. Instr. and Meth., A341, 431-435 (1994)
[5] O. chubar, P. Elleaume, J. chavanne, “A 3-Magnetostatics Computer Code for Insertion Devices” J. Synchrotron Rad. (1998), 5, 481-484