SUPERCONDUCTING UNDULATOR WITH VARIABLY POLARIZED LIGHT

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Abstract

This study investigates planar in-vacuo superconducting elliptically polarized undulators with periodic length of 5 cm (SEPU5) producing linearly and circularly polarized infrared rays or x-rays source. The vertically wound racetrack coil is chosen for the coil and pole fabrication of the SEPU5. When the up and down magnetic pole arrays with alternative directions rotated wires in the horizontal plane, an elliptical field radiates elliptically polarized light in the electron storage ring, the free electron laser (FEL), and the energy recovery linac (ERL) facilities. Meanwhile, an un-rotated wire magnet array is constructed together with the rotated wire magnet array on the same undulator is used to switch the linear polarization in horizontal and vertical, as well as the right- and left-circular polarization radiation. This investigation describes the main factors of the planar and helical undulator design for FEL and the concepts concerning the magnet array structures of the superconducting undulators.

INTRODUCTION

The circular polarization mode of the elliptically polarized undulator provides the high gain and high flux in the FEL scheme. Several schemes [1-4] have been developed to generate the function of linear and helically distributed fields, using electromagnets with copper coils, and hybrid or pure structures with permanent magnets in various configurations. These schemes, either with helical geometry, which combines separate horizontal and vertical devices, or with planar geometry with a variable phase, yield variably polarized light. A planar superconducting elliptical polarization undulator [5] with 5 cm period length (SEPU5) produces a helical field in the storage ring, and in the FEL or ERL accelerator facilities are developed. This magnet provides more intense right- and left-circularly polarized light, and is linearly polarized in the horizontal and vertical direction. Combining two magnet arrays with (inner magnet array) and without (outer magnet array) pole rotation in the same structure creates various tunable polarizations. The vertical-winding racetrack coil structure for the in-vacuo superconducting undulator [6] is chosen for the requirements of the tunable polarizations function. Therefore, given a periodic length of 5 cm and a gap of 13 mm and 23 mm for the outer and inner magnet array, respectively, the maximum magnetic flux densities in the helical undulator are B_z = 2.7 T and B_x = 0.54 T when the wires are rotated by 35^o[7]. When the SEPU5 operated with 100 MeV energy of the linac accelerator, the SEPU5 provides 1-10 μm circular polarization IR wavelength in the FEL facility for the user requirements in Taiwan. Additionally, the SEPU5 can also provide horizontal and vertical linear polarization in the energy ranges of 1-100 μm and 1-10 μm, respectively. This study describes concepts related to the elliptical, helical and linear polarization mode in the same undulator, and presents the design of the magnet array structures of the elliptical superconducting undulators. The use of two different excitation currents to generate the mechanism of the polarization switching in the right- and left-circular polarization radiation and linear polarization is discussed. Furthermore, the features of magnetic field and photon spectra on the in-vacuo superconducting elliptical polarization undulators are also elucidated. Finally, the photon flux in different polarization mode and the mechanism of the switching polarization radiation are discussed.

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DESIGN CONCEPT OF THE SWITCHING POLARIZATION MECHANISM

Two planar magnet arrays with period length of 5 cm comprise the superconducting elliptical polarization undulator (SEPU5) structure. The outer magnet array has a rotated pole [5,8] that the rotation angle is 35^o and the inner magnet array does not have a rotated pole [9]. The two magnet arrays are combined as in Fig. 1. According to this SEPU5 structure, the maximum magnetic force between the two magnet arrays is about 4.5 kg. However, each coil in every pole was divided by four parts to analysis the force in the local coil between the two magnets arrays. The maximum force is 10 kg in the local coil parts. Hence, the force between the local parts is not an issue on the magnet operation. The total energy of this magnet is 56 kJ. Table I lists the main design parameters of the superconducting elliptical polarized undulator.

Depending on the IRFEL requirement in NSRRC, the Rayleigh range Z_R is 1 m and the maximum optical beam waist $w_0 = (Z_R\lambda/\pi)^{1/2}$= 1.75 mm in the photon wavelength between 1-10 μm. Therefore, the undulator minimum gap was estimated as g_{min}= 5 w_0 + 2t = 13 mm. Where t denotes the thermal shielding and redundancy factor for the superconducting magnet operation. The excitation current J_i and J_o on the superconducting coil of the inner array and outer array is independent. In this structure, the polarization can be switched via different combinations of the two-excitation currents. Table II lists the features in the six types of polarization mode by different combinations of the two-excitation currents in the superconducting elliptical polarized undulator. The polarization modes are changed by the different

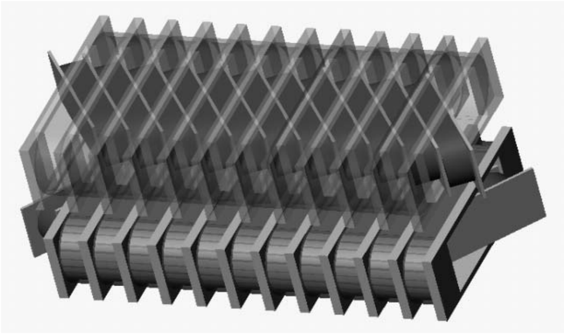

Figure 1: 3D schematic drawing of the superconducting elliptical undulator structure. The pole of the inner magnet array rotated 35° and the outer magnet array displays no pole rotation.

Table 1: Design parameters and features of the superconducting elliptical polarization undulator.

Number of poles	80
Periodic length λ_u (cm)	5
Magnet gap g of inner (outer) array (cm)	1.3 (2.42)
Physical length L (cm)	220
Inner pole rotation angle θ (deg)	35
Outer pole rotation angle θ (deg)	0
Field strength on coil B_s (T)	4.6
Maximum excitation current J_i (A/mm^2)	678
Maximum excitation current J_o (A/mm^2)	850
Total energy (kJ)	56.04
Force between magnet arrays $\{F_x,F_y,F_z\}$(Kg)	{1, 1, 4.5}

combination of the two-excitation currents. (1) When the inner and outer magnet array is excited by J_i =678 A/mm^2 and J_o =0, respectively, the SEPU5 produces an elliptical field with field strength of B_z = 1.34 T and B_x = -0.5 T. This operation mode is a right elliptical polarization mode. In this mode, high-energy photon is radiated by means of the higher harmonic spectra. (2) If the current J_o = -398 A/mm^2 was also excited on the outer magnet array, then the elliptical field becomes the helical field with the field strength of B_z = -B_x = 0.5 T. In this operation mode provide a right circular polarization. (3) If the current continuously increases to J_o = -620 A/mm^2, then the right circular polarization becomes the vertical linear polarization with the field strength of B_z = 0 T and B_x = -0.5 T. (4) If the current continuously increases to J_o = -750 A/mm^2, the vertical linear polarization becomes the left elliptical polarization with field strength of B_z = -0.3 T and B_x = -0.5 T. (5) If the current continuously increases to J_o = -850 A/mm^2, the left elliptical polarization becomes a left circular polarization with field strength of B_z = B_x = -0.5 T. (6) If the excitation current was set at J_i = 0, J_o = 678 A/mm^2, then the SEPU5 produces horizontal linear polarization with field strength of B_z = 1.8 T and B_x = 0. Table II lists the relationship between the polarization mode and the excitation current combination.

SPECTRA FEATURES OF THE SUPERCONDUCTING ELLIPTICAL UNDULATOR

The SEPU5 operates in a 100 MeV linac to provide the infrared source between 1-10 μm. Figure 2 shows the spectra features of the SEPU5 operated on a different polarization mode in the 100 MeV electron accelerator energy. The high radiation gain and flux occurs in the circular polarization mode that only exists in the first harmonic spectrum, Fig. 2 only showed the flux in the circular polarization mode and in the first harmonic spectra of the elliptical and linear polarization modes. However, in the storage ring or ERL accelerator facility, the higher harmonic spectra can be extended to higher energies. Figure 2 reveals a higher flux in the right- and left-circular polarization mode, and demonstrates that the energy spectrum range is between 1-8 μm. However, to extend the spectrum energy range, the elliptical polarization mode was selected to provide the energy range of 1-30 μm. However, the circular polarization rate is reduced in the elliptical polarization mode, and the photon flux is smaller than the circular polarization mode in the same energy range. Additionally, Fig. 2 shows that the SEPU5 also provides the horizontal and vertical linear polarization mode. If the SEPU5 was operated in the vertical (horizontal) polarization, the spectrum energy range will be located in the range 1-6 (1-60) μm. However, the photon flux is also slightly smaller than that in the elliptical polarization mode. If the higher harmonic spectra radiates from the SEPU5 in the 3 GeV storage ring or ERL, the energy can reach up to 4 keV. Figure 3 shows the higher energy photon in the soft x-ray region was radiated in the 3 GeV accelerator facilities.

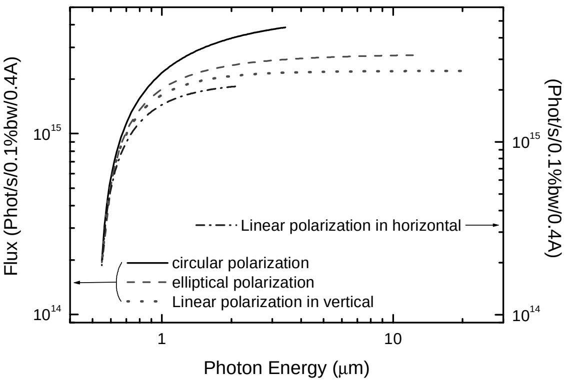

Figure 2: Spectra distribution of various polarization modes in the superconducting elliptical polarization undulator (SEPU5) was obtained in the 100 MeV electron linac.

Table 2: Combination of the excitation current for different polarization mode on the superconducting elliptical polarization undulator. Six polarization modes exist that are operated in the electron energy 100 MeV: Right Elliptical Polarization (REP), Left Elliptical Polarization (LEP), Right Circular Polarization (RCP), Left Circular Polarization (LCP), Vertical Polarization (VP) and Horizontal polarization (HP).

	REP	**LEP**	**RCP**	**LCP**	**VP**	**HP**
Excitation current J_i (J_o) (A/mm^2)	678 (0)	678 (-750)	678 (-398)	678 (-850)	678 (-620)	0 (678)
Magnetic flux density B_z (B_x) (T)	1.3 (-0.5)	-0.3 (-0.5)	0.5 (-0.5)	-0.5 (-0.5)	0 (-0.5)	1.8 (0)
Flux @ 1(6) μm (p/s/0.1%bwx10^{15})	1.7 (2.3)	1.9 (2.9)	2.2 (3.3)	2.2 (3.3)	1.7 (2.0)	1.7 (2.0)
Spectrum energy range (100 MeV) (μm)	30 – 1	7 – 1	8 – 0.96	8 – 0.96	6 – 0.99	60 – 1
Deflection parameter K_z (K_x)	6.3 (2.3)	1.3 (2.3)	2.3 (2.3)	2.3 (2.3)	0 (2.3)	8.4 (0)

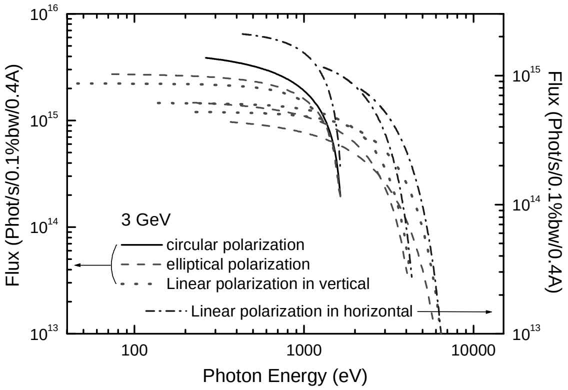

Figure 3: Spectra distribution obtained in the 3 GeV electron energy on various polarization modes.

CONCLUSION

It is possible and feasible to radiate the circular and linear in horizontal and vertical polarization light in an in-vacuo superconducting elliptical undulator. For the infrared ray FEL in a 100 MeV electron linac, the superconducting elliptical undulator with period length of 5 cm radiates the energy range between 1-30 μm in the elliptical polarization light or between 1-60 μm in the horizontal linear polarization light. The switch between all polarization modes does not involve mechanical movements and simply tunes the excitation current on the inner and outer magnet array. In addition, the in-vacuo superconducting elliptical undulator can also operate in the medium-accelerator storage ring or the ERL facility with shorter period length, and can use the higher harmonic spectrum to extend the energy range to the hard x-ray range.

ACKNOWLEDGEMENTS

The authors would like to thank the National Science Council of Taiwan for support of this research under Contract No. NSC93-2112-M-213-001. Mr. H. H. Chen and M. H. Huang are appreciated for discussing mechanical structure of the elliptical undulator.

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