CROSSED ELLIPTICAL POLARIZATION UNDULATOR

Shigemi Sasaki, Ross Schlueter, and Steve Marks
Lawrence Berkeley National Laboratory
1 Cyclotron Road, Berkeley, CA 94720

Abstract

The first switching of polarization direction is possible by installing two identical helical undulators in series in a same straight section in a storage ring. By setting each undulator in a circular polarization mode in opposite handedness, one can obtain linearly polarized radiation with any required polarization direction depending on the modulator setting between two undulators. This scheme can be used without any major degradation of polarization degree in any low energy low emittance storage ring.

1 INTRODUCTION

There are increasing demands among the synchrotron radiation users for utilizing not only the circularly polarized radiation, but also the linearly polarized radiation with fast switching of polarization directions.

An elliptical polarization undulator (EPU) is planned to be installed in the storage ring of Advance Light Source (ALS) [1]. Similar devices are also planned for other third-generation synchrotron radiation facilities. Those devices have a capability of generating both circularly polarized radiation and linearly polarized radiation by mechaninally changing the magnet phases. However, it is very difficult to change the polarity quickly due to the magnet motion mechanism. One possible solution to achieve the fast switching of polarization direction is to install two identical EPUs in series with an electromagnetic modulator in a same straight section of storage ring. The concept of crossed undulator was originated by Kim in order to produce various polarization states including elliptical polarization with two planar undulators [2]. A similar approach is used for analyzing a crossed EPU.

Assume the first EPU is set in a circular polarization mode with right-handedness, and the second is set in the mode with left-handedness. If an electron passes through the system of two EPUs with the setting mentioned above, the polarization vector of radiation is written as :

$$\varepsilon = \frac{1}{\sqrt{2}}\left(\varepsilon_- + e^{i\phi}\varepsilon_+\right). \qquad (1)$$

Here ε_- (ε_+) is the complex orthogonal unit vector of left (right) handed circular polarization [3]. The combination of right hand circular polarization and left hand polarization with the phase difference ϕ results in a linear polarization. The direction of polarization depends on ϕ. For example, the polarization direction is horizontal (vertical) when ϕ equals to zero (π).

As described in ref. 2, the phase ϕ can be changed by changing the path length of the electron between the two undulators. An electromagnetic modulator can be used for the rapid change of phase [4].

2 ANALYSIS

Figure 1 is a schematic drawing of the proposed system. The system consists of two identical EPUs, one of which is set in a opposite magnet raw phase from the other. For simplicity, the magnetic field of each undulator is assumed to be perfectly helical and the field of a single period (λ_M) modulator is assumed to be sinusoidal.

Let's assume that the first undulator EPU1 is set in a right hand circular polarization mode, and the second undulator EPU2 is set in the oposite. The wavelength of fundamental radiation peak in the forward direction is

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1+K^2\right), \qquad (2)$$

where λ_u is the magnetic period length, $\gamma=E/mc^2$, and

$K=eB_0\lambda_u/2\pi mc=93.4B_0[\mathrm{T}]\lambda_u[\mathrm{m}]$. (3)

Here, B_0 is the magnetic field, e and m are electron charge and mass, respectively.

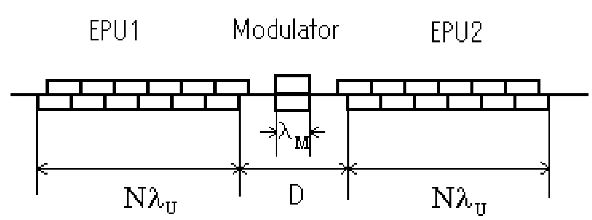

Figure: 1 Schematic drawing of the crossed EPU.

In this system the phase ϕ in Eq. 1 is:

$$\phi = \frac{2\pi}{\lambda}\left(N\Delta L + \Delta L_M + \frac{D}{2\gamma^2}\right). \qquad (4)$$

Here, ΔL is the path difference between an electron and a photon in the undulator, ΔL_M is that in the modulator, and D is the distance between two undulators, respectively. Since the fields are helical in undulator and sinusoidal in modulator, one can obtain the phase ϕ using the relation in Eq. 2 as follows:

$$\phi = \frac{\pi}{\lambda\gamma^2}\left\{N\lambda_u\left(1+K^2\right)+\lambda_M\left(1+K_M^2/2\right)+D\right\}$$
$$= 2\pi\left\{N+\frac{\lambda_M\left(1+K_M^2/2\right)+D}{\lambda_u\left(1+K^2\right)}\right\} \qquad (5)$$

Here,
$K_M = 93.4 B_M[\mathrm{T}]\lambda_M[\mathrm{m}]$, (6)
where B_M is the peak magnetic field of modulator. In order to change the phase, one has to change the distance D mechanically or change K_M^2 by changing the magnetic field of modulator.

3 DEGREE OF POLARIZATION

In an actual storage ring, electron beam has a finite emittance so that some electrons in the beam travel with angular divergence and energy deviation. If the angular distribution of electrons is Gaussion, the mean square phase deviation is written as:

$$\left\langle(\Delta\phi)^2\right\rangle = \left\langle\left(\phi-\langle\phi\rangle\right)^2\right\rangle$$
$$= \left(\phi_0\frac{\sigma_\lambda}{\lambda}\right)+2\left(2\pi\eta\frac{\gamma^2\sigma_\theta^2}{1+K^2}\right)^2, \qquad (7)$$

where $\sigma_\lambda^2 = \left\langle(\Delta\lambda)^2\right\rangle$, $\sigma_\theta^2 = \left\langle\left(\theta^2\right)\right\rangle$, ϕ_0 is the ideal phase given by Eq. 5, and

$$\eta = N+\frac{\lambda_M+D}{\lambda_u}. \qquad (8)$$

By using Eq. 7, the degree of resulting polarization is [2]:

$$P = 1-\frac{\left\langle(\Delta\phi)^2\right\rangle}{2}$$
$$= 1-\frac{1}{2}\left(\phi_0\frac{\sigma_\lambda}{\lambda}\right)^2-\left(2\pi\eta\frac{\gamma^2\sigma_\theta^2}{1+K^2}\right)^2 \qquad (9)$$

As one can see from Eq. (9), the degree of polarization decreases when σ_λ is large due to the large energy spread of electron or large band width of monochromator. However, the degradation is much serious due to the third term in Eq. (9). Therefore, this scheme cannot be used for high energy or high emittance storage ring.

4 EXAMPLES

The Advanced Light Source (ALS) is a low emittance, low energy storage ring. It is operated at an electron energy 1.5 GeV, and the natural emittance is 4 nm-rad. The beam divergence in a straight section for insertion device is 1.9x10^{-5} rad. The energy spread of electron beam is smaller than 1x10^{-3}.

An EPU which will be installed in ALS has the period length of 5 cm, and the number of period N is 37. The achievable maximum K value is 2.5. If we construct the proposed system with two identical EPUs in a same straight section of ALS, η in Eq. (8) is 40 by assuming $\lambda_M = \lambda_u$ and $D = 2\lambda_u$. In our case, the second term in Eq. (9) is negligibley small. Therefore, the polarization is witten as:

$$P \approx 1-\left(80\pi\frac{\gamma^2\sigma_\theta^2}{1+K^2}\right). \qquad (10)$$

In table 1, parameters of example system and the resulting polarization are listed.

Table 1
ALS and EPU parameters

E[GeV]	1.5	
σ_θ[rad]	1.9x10^{-5}	
σ_λ/λ[%]	0.08	
N	37	
λ_u[cm]	5.0	
λ_M[cm]	5.0	
K	1.0	2.5
λ[nm]	5.8	10.15
ε[eV]	214	122
P[%]	84.7	98.8

The degree of polarization is 98.8% at assumed maximum K value of this system.

5 DISCUSSIONS AND CONCLUSIONS

A proposed crossed EPU system can be used in photon energy ranges below 200 eV with reasonably high polarization degree. Although this system can be used above 200 eV by selecting a K value smaller than 1, the degree of polarization decreased rapidly when K approaches to zero. For the purpose of higher polarization degree in lower photon energy range, a longer magnetic period length and smaller number of period are recommended. It can be achieved with the cost of reduction of peak brightness.

An advantage of the proposed device is that one can obtain a purely monochromatic radiation with no higher harmonics on axis. The reason is that the radiation from each undulator is a circularly polarized radiation with no higher harmonics.

A fast switching of polarization direction can be achieved by using an electromagnetic modulator. Alternating switching between horizontal and vertical polarization may be useful for investigating the property of surface or interface of material. One can also used a circularly polarized radiation by setting both EPUs in the same helicity mechanically.

Utilization of two EPUs with a modulator as a crossed EPU is proposed for generating a linearly polarized radiation with the fast switching capability and no higher harmonic contamination in the spectrum. This scheme is usefull in any third generation low energy (<2 GeV) storage ring.

ACKNOWLEDGEMENTS

Authors thank K.-J. Kim for helpful discussions with him. This work was supported by the Director, Office of Energy Research, Office of Basic Energy Science, Material Science Division, U. S. Department of Energy, under Contract No. DE-AC03-76SF00098.

REFERENCES

[1] S. Marks, C. Cortopassi, J. DeVries, E. Hoyer, R. Leinbach, Y. Minamihara, H. Padmore, P. Pipersky, D. Plate, R. Schlueter, A. Young, these Proceedings.
[2] K. J. Kim, Nucl. Instrum. Meth. **219** (1984) 425.
[3] J. D. Jackson, Classical Electromagnetics, Second Edition (John Wiley and Sons, Inc., New York, 1975, p275).
[4] R. Savoy, K. Halbach, in Proc. of the 1991 IEEE Particle Accelerator Conference, page 2718.