Conceptual Design for the SRRC Elliptically Polarizing Undulator EPU5.6. Part I: Magnetic Configuration and Merit Function Optimization

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Abstract

The Synchrotron Radiation Research Center (SRRC) as one of the third generation light source facilities is going to install a dual-device equipped with two 4-meter-long Sasaki-type elliptically polarizing undulators (EPUs) in the near future. One of the EPU magnets to be mounted on the dual-device will have a period length of 56 mm and the other one of about 100 mm. In part I of the conference paper, we propose our conceptual design for the first one, the device EPU5.6, with emphasis on the design of its magnetic configuration and on the determination of its maximal achievable spectral merit function.

1 INTRODUCTION

Some of the third generation light source facilities are now being routinely operated in many laboratories all over the world, in which the undulator undoubtedly plays the dominant roll for generation of the bright synchrotron light. Moreover, high degree of polarized light can be generated by variation of the undulator magnetic configurations[1], which indeed opens the possibility for the synchrotron light source users to perform some experiments which were impossible before, due to the strong requirements on the high degree of circular polarization as well as on the brilliant spectral intensity of the synchrotron light. On the other hand, the elliptically polarizing undulator (EPU) proposed by Sasaki[2] is one of the most promised schemes for generation of the intensive undulator light with abundant states of polarization.

In the near future, two of the Sasaki's type device will be installed in the SRRC storage ring and share one straight section to form a dual-device for providing the polarized spectrum in the photon energy range from 5 eV to 1400 eV. Similar projects are also aggressive in progress in some other laboratories, in particular in ALS[3] and BESSY II[4]. Here, we report our conceptual design for the elliptical polarizing undulator EPU5.6 for generation of the polarized radiation from 80 eV to 1400 eV, with emphasis on its design of the magnetic configuration and on the determination of its maximal achievable spectral merit function.

2 MAGNETIC CONFIGURATION

2.1 Periodic Structure:
The 4-m-long Sasaki's type elliptical polarizing undulator to be constructed for the SRRC storage ring has a period length of 56 mm, therefore named as EPU5.6, and consists of four (4) longitudinal movable magnetic arrays which assembled with pure NdFeB permanent magnetic blocks. The effective period number will be larger than 68. The magnetic blocks have a square cross-section of 40 mm x 40 mm which was determined with compromise among the saturation nature of the on-axis peak field strength, the flexibility for the magnetic block sorting, and the feasible cross-section of the undulator vacuum chamber under considerations on mechanical deformation and pumping efficiency. The minimum operating gap will be 18 mm with concern on the reasonable electron beam injection efficiency and stored beam life-time. However, the mechanical structure as well as drive system will be designed to have the capability to drive the magnetic gap down to 14 mm gap.

The on-axis magnetic field profile for an elliptically polarizing undulator can be expressed[2] as

$$B_x = -\hat{B}_x \sin\left(\frac{\phi}{2}\right) \cos\left(\frac{2\pi}{\lambda_u} z + \frac{\phi}{2}\right) \quad (1)$$

$$B_y = +\hat{B}_y \cos\left(\frac{\phi}{2}\right) \sin\left(\frac{2\pi}{\lambda_u} z + \frac{\phi}{2}\right), \quad (2)$$

where λ_u is the magnetic period length of the device, and ϕ the phase shift between the upper-front/lower-back and upper-back/lower-front magnetic arrays. $\hat{B}_x$ and $\hat{B}_y$ are the on-axis achievable maximal peak field strength of the horizontal and vertical components by tuning the phase between magnetic arrays. The on-axis peak field strengths were calculated by using the code USEM with assumption that the NdFeB permanent magnetic blocks being current sheet equivalent material, which are 6.72 and 4.53 kGauss of the vertical and horizontal amplitudes for the device EPU5.6 at 18 mm gap, respectively. Remanence of 11000 Gauss for the permanent magnetic blocks was adopted for the calculation. The device efficiency η_{max} defined as $\hat{B}_x/\hat{B}_y$ at the minimal operating gap is equal to 0.67, which is usually proportional to the magnetic period length. A cross-check was performed by using the commercially available 3D magnetostatic code OPERA/TOSCA. A less than 2% of discrepancy was

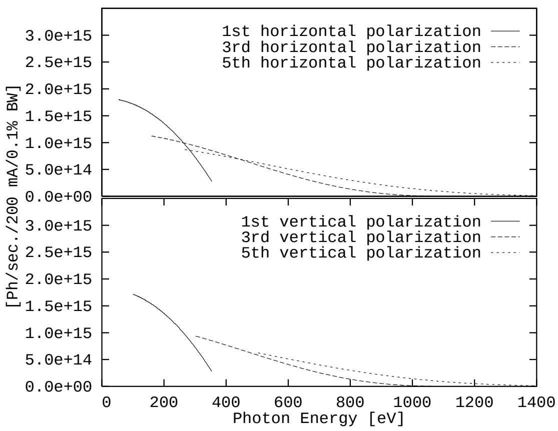

Figure 1: Linear polarized undulator spectrum for the SRRC device EPU5.6.

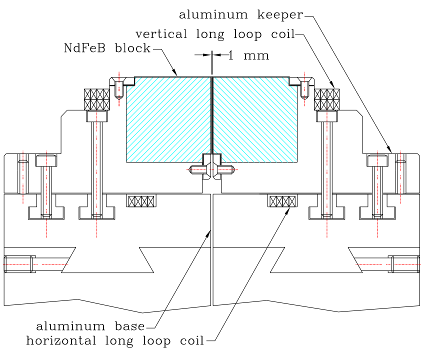

Figure 2: Side view of the SRRC device EPU5.6 with long-loop correction coils.

achieved, which gives the guide-line for the uncertainty of the magnetic field modelling and provides the margin for over-design. The achievable maximal values of wiggler parameters $\hat{K}_y$ and $\hat{K}_x$ which characterize the spectral distribution of the horizontal and vertical linear polarized undulator light are larger than 3.52 and 2.37, respectively. The calculated spectrum for the total linear polarized flux emitted from a 1.5 GeV, 200 mA electron beam as a function of the photon energy is given in the Fig. 1.

The polarization state of the synchrotron light emitted from the device EPU5.6 will be adjusted by tuning the phase shift among the four individual magnetic arrays. Due to the fact that a strong attractive or repulsive force exists between the front and back magnetic arrays, a small slit between them is necessary to provide smooth movement of the individual magnetic arrays along the longitudinal direction freely. In our design, one(1) mm slit between the magnetic arrays will be allowed, as shown in Fig. 2, which is paid in terms of separation of the vertical peak magnetic field strength, as shown in Fig. 3.

2.2 Integrated Multipole Compensator

The ambient field distribution in the storage ring tunnel may be quiet different in comparison with that in the magnetic measurement laboratory, if a quantity of 100 Gauss-cm of integrated dipole steering to be considered. A fine-compensation of the device remaining dipole steering with beam test is usually necessary, and two pairs of long-loop correction coils will be reserved for this purpose and mounted around the magnetic arrays, as drawn in Fig. 2, which will be provided for correction of the vertical as well as horizontal beam steering. Design of the built-in air-coil end correctors with combined function to serve for purpose of dynamic tuning of the device gap or array phase is in progress. Similar to the conventional pure type undulator, an EPU magnetic structure can be terminated by a 1/8 period length block in both ends of the individual magnetic arrays for smooth entrance of the electron beam into the device and exit from it. As well known, with this simplest end scheme, the moving axis of the electron beam will have a gap-dependent offset to the device longitudinal-axis in the horizontal projection plane. But, there is no orbit offset in the vertical projection plane. An adiabatic entrance/exit of the electron beam into/from the device in both projection planes can be realized by proper modification of the block sizes of the first/last period[5] at the sacrifice of the number of the effective magnetic period.

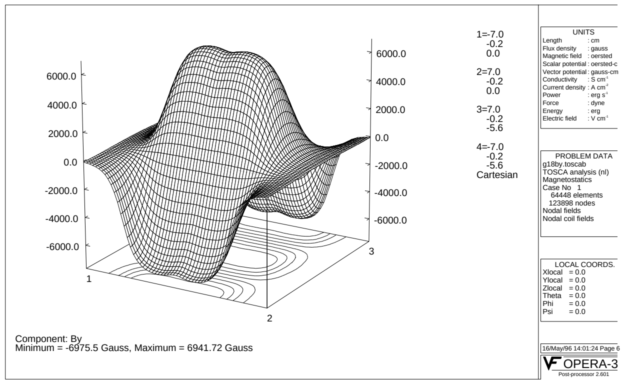

Figure 3: Profile of the vertical magnetic field in the middle plane (x-z plane with y=0).

However, in our end design, we would rather to reserve the possibility for post-compensation of the integrated multipole components after assembly of the magnetic arrays on the backing beam and the support frame, which result mainly from the unavoidable magnetic field errors due to remanence scattering of the individual permanent magnetic blocks or/and mechanical assembly tolerances. We proposed a pure type end scheme which allows us to adjust the vertical position of the first/last blocks for compensation of the remaining dipole steering. Moreover, a pure type magic fingers[6] will be equipped above the end blocks for compensation of the integrated quadrupole components.

3 MERIT FUNCTION OPTIMIZATION

The total spectral flux [photons s^{-1} (0.1%)$^{-1}$] of the n-th odd harmonic emitted from a N-period Sasaki-type EPU device by beam current I_b can be expressed as follows:

$$F_n = 1.431 \times 10^{14} \cdot \frac{nNI_b^{[A]}}{1+\frac{1}{2}K_{eff}^2} \cdot \left(K_y^2[JJ_-]^2 + K_x^2[JJ_+]^2\right), \tag{3}$$

with

$$[JJ_\mp] = J_{\frac{n+1}{2}}\left(\frac{n}{4}D\right) \mp J_{\frac{n-1}{2}}\left(\frac{n}{4}D\right),$$

and

$$D = \frac{K_y^2 - K_x^2}{1+\frac{1}{2}(K_y^2+K_x^2)}.$$

The conventional notations are used here. Finally, the normalized Stokes parameter s_3 is expressed as

$$s_3 = 2\epsilon\frac{[JJ_-]\cdot[JJ_+]}{[JJ_-]^2+\epsilon^2[JJ_+]^2}. \tag{4}$$

The merit flux $s_3^2 F_n$ is usually maximized for optimization of the experimental signal-to-noise ratio, while the Stokes parameter s_3 should not be small than 75%. This criterion can be adopted for examination of a device performance. The device achievable maximal merit flux will be determined by mechanically shift of the phase between arrays, or equivalently by variation of the ellipticity or more concretely the ratio between horizontal and vertical magnetic field strength ϵ, while the effective wiggler parameter K_{eff} (equal to $\sqrt{K_x^2+K_y^2}$) is kept constant for maintenance of the resonance harmonic energy. Here, we plot only the final results of the maximal merit flux, as shown in Fig. 4. The correspondent normalized Stokes parameter s_3 and the optimized ellipticity $\epsilon_{n,opt}$ are also given.

The discontinuities in the curves of Fig. 4 indicate that there is a maximal achievable value of $K_{eff,c}$ able to satisfy the optimized conditions mentioned above due to constraint on the minimum operating gap:

$$K_{eff,c} = \hat{K}_x\sqrt{\frac{1+\epsilon_{n,opt.}^2}{\eta_{max}^2+\epsilon_{n,opt.}^2}}. \tag{5}$$

For optimization of the merit flux, the optimized ellipticity $\epsilon_{n,opt.}$ is insensitive to the quantity of K_{eff} and equal to one for the first harmonic circular polarized light and approximately equal to 0.4 and 0.3 for the third and fifth elliptically polarized light, respectively [4]. It is worth to point out that the optimized ellipticity ϵ_{opt} is also gap-dependent. Therefore, it is necessary to re-optimize the phase between arrays after gap tuning for maintenance of the optimization condition. A more detailed discussion on the characterization as well as optimization of the spectral polarization performance and on survey of the polarization map for an EPU device will be discussed elsewhere.

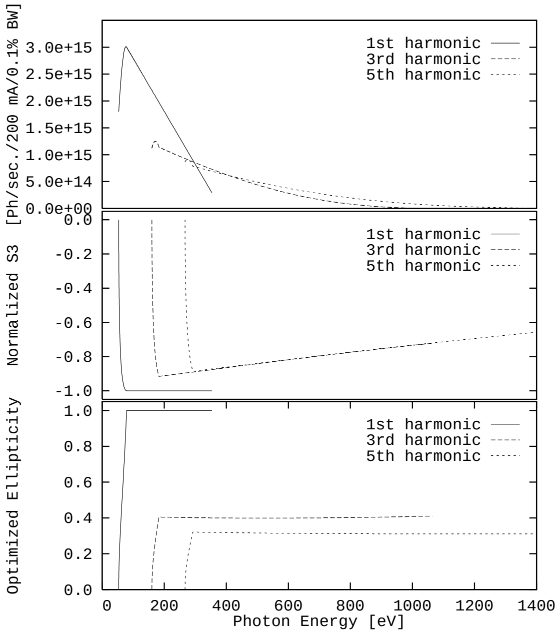

Figure 4: Elliptically polarized undulator spectrum, under condition of the maximal achievable merit function, for the SRRC device EPU5.6.

4 CONCLUSION

In part I of this conference paper, we emphasize our conceptual design for the SRRC elliptical polarizing undulator EPU5.6 on the design of the magnetic configuration and on the determination of the maximal achievable spectral merit function. The spectral performance is given.

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5 REFERENCES

[1] P. Elleaume, ”Helios: a New Type of Linear/Helical Undulator”, Synchrotron Rad. 1, p19-26, 1994, and references therein.

[2] S. Sasaki, ”Analyses for a Planar Variably-Polarizing Undulator”, Nucl. Instrum. & Mech. A347, p83-86, 1994.

[3] S. Marks et al., ”ALS EPU5.0: Magnetic Structure Conceptual Design Review”, 1995.

[4] J. Bahrdt, M. Scheer, ”An Elliptically Polarizing Undulator for BESSY II: UE-56”, 1995/1996.

[5] M.M Nikitin and G. Zimmerer, ”Use of Undulators for Spectroscopy without Monochromators”, Nucl. Instrum. & Mech. A246, pp. 94-98, 1986.

[6] E. Hoyer et al., ”ALS Multiple Trim, or ”Magic Fingers”, Magnet for Insertion Device Field Integral Correction”, Rev. Sci. Instrum. 66(2), pp. 1901-1903, 1995.