MAGNET BLOCK ARRANGEMENTS FOR THE APPLE-II ELLIPTICALLY POLARIZED UNDULATOR*

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Abstract

The uniform field region (magnetic field roll-off) of the distributions of horizontal and vertical fields in the elliptically polarized undulator (EPU) of the APPLE-II structure is too short. Hence magnet block arrangements such as (1) the magnet block magnetized with a tilt angle, (2) a step shim of thickness 0.5 mm placed at the magnet edge, and (3) shortening the transverse dimension of the magnet block have been investigated to enlarge the uniform field region. The advantages and disadvantages of these block arrangements are discussed. The pure and hybrid structure of the EPU with an optimized end-pole design and the merit of flux as a function of varied phase have also been studied.

INTRODUCTION

Elliptically polarized undulators (EPU) are in widespread use in synchrotron light sources, especially for photon energies in the soft x-ray region. Many schemes have therefore been used to generate a helical or elliptical field distribution, using both electromagnets and permanent magnets in various configurations. At an early stage, the magnet array was made in two dimensions, but this arrangement not only complicated the magnetic field measurement and installation but also prevented a decreased magnet gap. Hence, various ‘planar’ EPU structures were developed to produce an elliptically polarized photon source. The first ‘planar’ EPU structure (HELIOS) was proposed by ESRF [1]; the lack of symmetry of this device produced a second-order effect, and the field strength and the polarization rate are too small. A modification of the HELIOS device to the planar helical undulator was thus proposed [2]. Although that modification of the HELIOS device eliminated the second-order deflections that had existed in the HELIOS structure, the helicity became fixed. A further planar EPU device APPLE II [3] was developed in which each of the four arrays has a conventional Halback structure. The APPLE-II device can not only provide polarized photons of any kind [4] but also obtain strong field strength and the greatest polarization rate. The drawback of the APPLE II structure is that the uniform field region is too short; a structure comprising six magnet arrays [5] was thus proposed by the SPring-8 team. Although this structure has a wider region of uniform field, the structure precludes both pure vertical and horizontal polarization unless at least five magnet arrays are changeable. Because the APPLE-II structure has, apart from the short region of uniform field, many advantages over other structures, we focused our attention on increasing the uniform field region in the APPLE-II structure. We investigated various mechanisms to solve the uniform field in the APPLE-II structure. As the on-axis integral field and the maximum merit of flux become altered when the phase shift and magnet gap are varied, we studied the end-pole design in the pure and hybrid APPLE–II structures and the merit of flux as a function of difference gap and phase. This work enables us to obtain both a small variation of the first and second field integrals and the maximum merit of flux in a varied polarization mode on varying the magnet gap and the phase shift.

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MAGNET BLOCK ARRANGEMENTS

To solve the problem of the short region of uniform field in the APPLE-II structure, several methods have been proposed, shown in Fig. 1: (a) a step shim with thickness 0.5 mm at the edge of the magnet block; (b) a 10-deg magnetized tilt angle in the vertical field magnet block (V-block), and (c) a decreased dimension of the magnet block in the horizontal axis. Our analysis of the uniform field region in these structures follows.

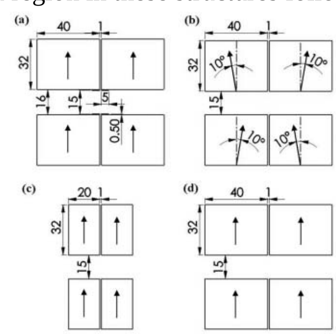

Figure 1: Several methods applied to increase the homogeneity field region: (a) a step shim of thickness 0.5 mm at the block edge, (b) a 10-deg magnetized tilt angle in the V-block, (c) a shortened magnet block dimension in the horizontal axis, and (d) the original block without a step shim.

0.5-mm step shim at the magnet edge

The step shim on magnet edge was applied in NSRRC EPU5.6 [6] that has been installed in the TLS. Figure 2 reveals the field roll-off distribution on the transverse x-axis with and without the 0.5-mm step shim at the magnet edge. The uniform field region of vertical field B_z in the horizontal x-axis is obviously wider than that of the original block without the step shim, but the horizontal field B_x in the horizontal x-axis is a little less than that without the step shim. The uniform field region of the vertical field remained almost constant when the polarization was varied from horizontal linear to circular. The uniform field region (at phase 0) is about ±20 mm and ±2 mm under field homogeneity $\Delta B/B \leq 0.8$ % with and without the step shim, respectively. Figure 3 reveals that the central field variation of the normal (skew) multipole strength in case of Fig. 1(a) is smaller (larger) than the case of Fig. 1(d) when the phase is varied, but the integral field variation of the normal (skew) strength is a little different (not different) between the cases of Fig. 1(a) and 1(d), as revealed in Fig. 4. The EPU5.6 commissioning results in the TLS storage ring show that the tuning shift and the beam size variation are well controlled [7]. The 0.5-mm step shim can thus widen the uniform field region of the vertical field, and the magnet blocks and field quality are readily constructed and controlled. The drawback of this method is that the 0.5-mm step shim increases the 1-mm magnet gap to accommodate the beam duct and decreases the magnetic field strength. The maximum magnet field strength at the same magnet gap is 0. 68 T (0.73 T) for the magnet block with (without) the step shim.

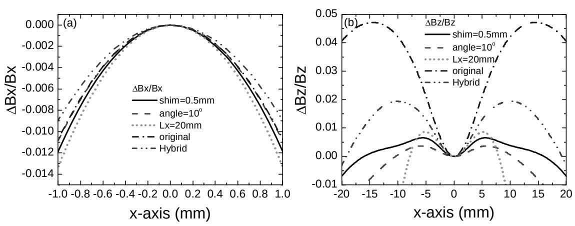

Figure 2: Roll-off of the peak field at (a) $P=\pi$ (Bx) and (b) $P=0$ (Bz) distributed in the horizontal x-axis, in which phase $P=2\pi(\Delta z/\lambda u)$, Δz is the phase shift distance in the longitudinal axis and and λu is the periodic length.

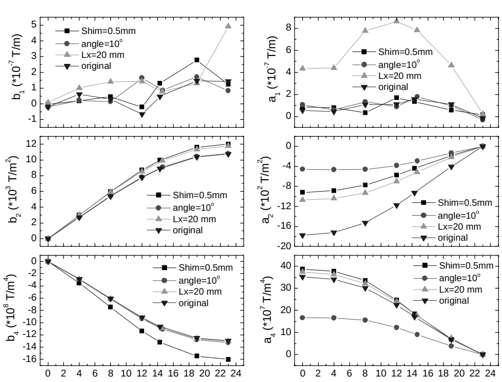

Figure 3: Multipole field variation of the central pole as a function of phase shift under various magnet block arrangements, with bn and an as the skew and normal components, respectively.

10-deg magnetized tilt angle in the V-block

To maintain the same magnet gap as that without the 0.5-mm step shim, a 10-deg magnetized tilt angle in the V-block (as shown in Fig. 1(b)) can also solve the short region of uniform field for the vertical field. In this case, the uniform field region of the vertical (horizontal) field Bz (Bx) in the horizontal x-axis is also improved; Fig. 2 reveals that the uniform field region exists ±15 mm (±0.85 mm) under a field roll-off $\Delta B/B \leq 0.8\%$ at phase $P=0$ (π). The uniform field region of Bz and Bx is altered a little as for the step shim when the phase was varied. Figure 3 reveals that the central field variation of normal and skew multipole components is a function of the phase shift. The variation of the multipole components is smaller than that for the step shim and without the step shim, but this method fail to improve the uniform field region of the horizontal field Bx in the transverse x-axis. Figure 4 reveals the integral normal and skew multipole components of the field strength of Bz and Bx for a varied phase shift. The integral skew components are not altered when the phase changes, the normal components vary a little but much less than that of the original and the other methods.

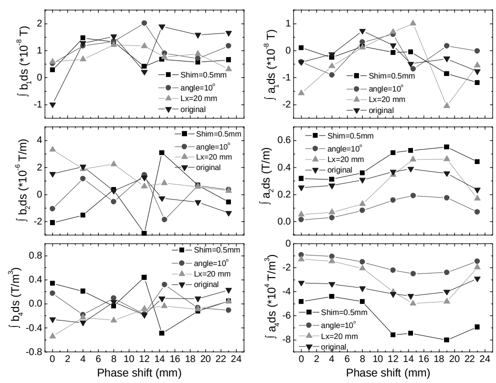

Figure 4: Integral multipole field variation as a function of phase shift for various magnet block arrangements.

Shortening magnet block dimension

Another method to increase the uniform field region is to shorten the block dimension (see Fig. 1(c)) in the transverse x-axis. This method can decrease the two-peak field at both sides of the magnet block, and the uniform field region can be broader than in the case of Fig. 1(d), but the peak field Bo became 10 % smaller than without shortening the block dimension. We hence increased the magnet height to compensate for the 10 % smaller peak field strength in the shortened magnet block. This method likewise fails to widen the uniform field region of the horizontal field Bx in the transverse x-axis. Figure 2 also reveals the effective field region compared with that in the other method. The uniform field region exists ±9 mm under a field roll-off $\Delta B/B \leq 0.8$ % at phase $P=0$. Figure 3 reveals the central field variation of the multipole components that is smaller than that of the original block when the phase was altered, and Fig. 4 shows the variation of integral normal components to be less than that of the original block.

END-POLE DESIGN

A satisfactory end-pole design maintains a small integral field variation when the magnet gap or the phase shift is altered. Figure 5 reveals an optimized end-pole design and a magnet arrangement with a magnet gap 15 mm and a periodic length 46 mm for the magnet V-block magnetized at 10 deg with respect to the vertical direction. The on-axis integral field variation for varied phase and magnet gap has maintained within 15 G-cm after the optimized dimensions of the magnet block and the distance between the end magnet block shows in Fig.5. We investigated also the hybrid and pure structure of the EPU4.6. The central peak field is a little larger than that of the pure structure of the original block, but the uniform field region of the vertical field in the hybrid structure is wider than for the pure structure, shown in Fig. 2. However, the on-axis integral field variation of the hybrid structure is bigger than for the pure structure when the magnet gap or phase is altered.

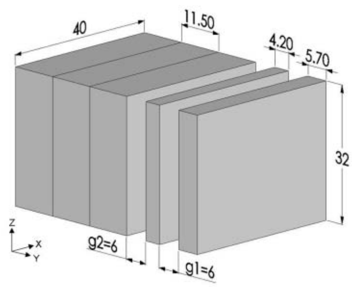

Figure 5: Dimension of optimized magnet blocks and the distance of the end-pole design.

MERIT OF FLUX FOR VARIED PHASE

If we try to obtain the merit of flux ($P^2\varphi$, in which P is the polarization rate and φ is the photon flux) at circular polarization (B_x=B_z, B_x and B_z are out of phase) in varying the gap to tune the photon energy, the phase shift should be varied with the magnet gap. Figure 6(a) shows the relation between phase shift and magnet gap in the circular polarization condition (B_x=B_z) and with linear polarization at 45^o. If we seek a large merit of flux on varying the gap, the phase should be altered as a function of that magnet gap, the same as for the EPU operated in the elliptically polarized mode. Figure 6 reveals that the merit of flux for phase-dependent is twice as large as that for phase-fixed when the magnet gap is varied. Moreover, if we consider the effect of the phase error and the energy spread, the flux in the higher harmonic spectrum becomes decreased. The phase error after field shimming is about 3 deg and the energy spread is about 0.1 % of the storage ring. Figure 7 shows the calculation of the flux decrease ratio and indicates the spectrum harmonic number of the APPLE II structure at n=11, the flux thus becomes decreased to 0.25.

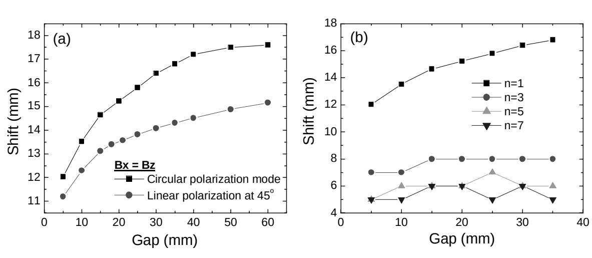

Figure 6: Relation between phase and gap at the maximum merit of flux in the condition (a) circular polarization (Bx=Bz and out of phase) and linear polarization at 45 o (135 o) (Bx=Bz and in phase), (b) various harmonic numbers for elliptical polarization (Bx≠Bz and out of phase) mode.

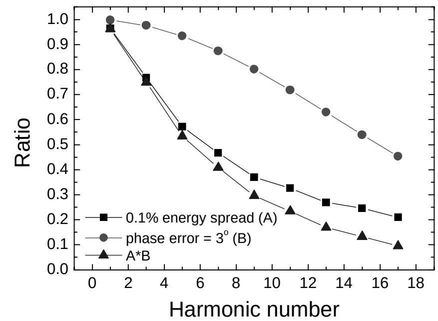

Figure 7: Flux decrease ratio as a function of the harmonic number under a phase error 3 deg, energy spread 0.1%, and the combination factor of phase error 3 deg and energy spread 0.1%.

CONCLUSION

Various magnet block arrangements have been investigated to widen the homogeneity field region of the APPLE-II structure. The 10-deg magnetized tilt angle in the V-block seems optimal to enhance the homogeneity field region, and the variation of the multipole components is smaller than that of other methods when the phase was altered. The integral skew components are zero because of the even-pole structure for the horizontal field of Bx (odd-pole structure in the vertical field of By). In the APPLE-II structure EPU, a reasonable harmonic number can be used up to n=11 when we consider the effect of the phase error and the energy spread.

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