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ELLIPTICALLY POLARIZING UNDULATOR DESIGN FOR PAL-XFEL

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Abstract

Elliptically polarizing undulator (EPU) is under consideration as after-burner for the PAL-XFEL soft X-ray beamline to control the FEL polarization. In the soft X-ray line, seven planar undulators with a 35 mm period and a 5 m length are in operation. To provide a polarization control of the FEL in the 1 to 3 nm wavelength, we compare the two types of EPUs, APPLE-II, and APPLE-X. The *K* value ranges for various operation modes are numerically studied for two undulator periods, 35 and 40 mm, of these EPU types.

INTRODUCTION

PAL-XFEL is an XFEL facility with two user beamlines [1, 2]. The hard X-ray beamline started user operation in 2017 with 0.1 to 0.7 nm wavelength. The soft X-ray line starts user operation recently with 1 to 3 nm wavelength. Both beamlines have planar undulators with periods of 26 and 35 mm for the hard and soft X-ray lines, respectively [3]. The undulators are hybrid types and the vertical magnet gaps are variable. The magnet material is NdFeB and the pole is FeCo. The parameters of the PAL-XFEL undulator systems are summarized in Table 1.

Table 1: PAL-XFEL Undulator System Parameters

Parameters	HXU	SXU
Period	26.0 mm	35.0 mm
K	1.973	3.321
B_{eff}	0.812 T	1.016 T
Minimum Magnet Gap	8.3 mm	9.0 mm
Segment Length	5 m	5 m
Number of Segments	20	7
Undulator Type	Planar	

The soft X-ray beamline is branched at the 3 GeV point of the PAL-XFEL main linac. At the entrance of the undulator line, the electron beam energy is controlled between 3 and 3.15 GeV. Figure 1 shows the required *K* values to provide XFEL wavelengths between 1 and 3 nm with the electron beam energy range.

Two EPU types are in use or under construction for soft X-ray FEL. FERMI@Elettra uses APPLE-II type undulators as radiator [4], and SwissFEL is constructing APPLE-X undulators for the Athos beamline [5]. In this proceeding, we review the EPU types and undulator period to fulfill the requirements of the polarization of the PAL-XFEL soft X-ray beamline.

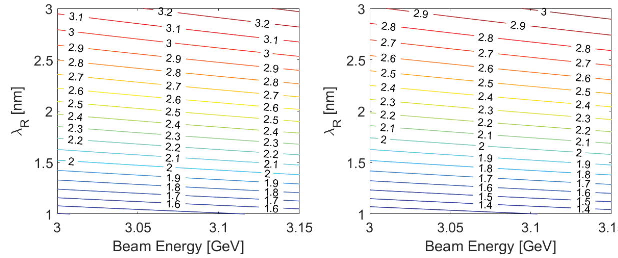

Figure 1: Undulator deflecting parameter *K* requirements to satisfy the PAL-XFEL soft X-ray beamline parameters, photon wavelength 1 to 3 nm and electron beam energy 3 to 3.15 GeV, for the cases of 35 mm undulator period (left) and 40 mm period (right).

OPERATION MODE OF EPUS

Design Parameters

For the APPLE-X type, the vacuum chamber is round. The magnet structures can be positioned near the center, and therefore the deflecting parameter *K* can be strong. Four magnet arrays are moved individually in the radial direction to change the magnet gap. The arrays can also be moved individually in the longitudinal direction to change the phase.

For the APPLE-II type, the vacuum chamber is flat, and the present design of the PAL-XFEL undulator chamber can be used without modification. However, the deflecting parameter *K* is weaker. For the magnet gap change, two magnet arrays adjacent each other horizontally are moved together. All of the four arrays can be moved individually in the longitudinal direction to change the phase.

These EPU types are modeled with the RADIA code [6] as shown in Fig. 2. SmCo magnet material is assumed for APPLE-X and NdFeB is assumed for APPLE-II. For the APPLE-X design, the parameters of the SwissFEL Athos undulator [7] are considered. For the APPLE-II design, the magnet structure and material used at PLS-II are considered. Since the magnet of APPLE-X is placed near the beam axis, the material more resistive to radiation damage is used. The magnets of APPLE-X are magnetized in the radial direction, and those of APPLE-II are in the vertical direction. In the following sections, the undulator parameters of these two EPU types are compared.

The phase dependence of *K* values in the elliptical modes for two periods, 40 and 35 mm, of APPLE-X and APPLE-II undulator types, at the minimum magnet gaps, 3 mm for APPLE-X and 9 mm for APPLE-II, are compared in Fig. 3. For the 3 mm gap of APPLE-X, the maximum chamber radius is 4.5 mm. For APPLE-X, the *K* values are about 3.4 and 2.6 for 40 and 35 mm periods, respectively. For APPLE-II, the *K* values are about 2.7 and 2.1 for 40 and

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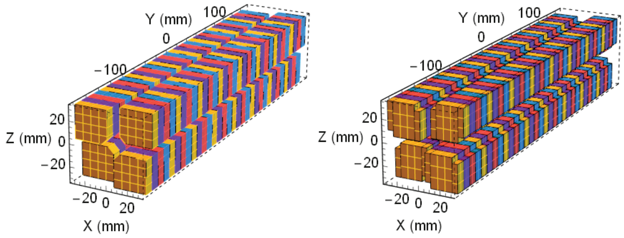

Figure 2: Radia models for APPLE-X (left) and APPLE-II (right) type undulators.

35 mm periods. In the elliptical mode, the K value changes only slightly through the phase.

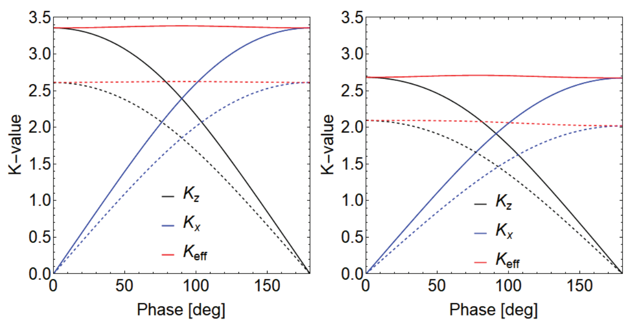

Figure 3: Phase dependence of K values for the cases of 40 mm (solid lines) and 35 mm (dashed lines) periods in the elliptical modes. Two undulator types, APPLE-X (left) and APPLE-II (right), are compared.

Figure 4 shows the phase dependence of K values of the APPLE-II with 9 and 20 mm magnet gaps in the elliptical modes. When the gap is changed from 9 to 20 mm, the K values are reduced from about 2.6 to below 1.5. Besides, the K value changes depending on the phase because the magnet arrays are moved only vertically while the horizontal positions are fixed.

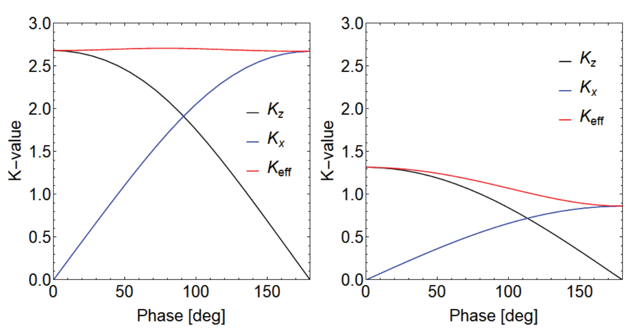

Figure 4: Phase dependence of K values of the APPLE-II with two deferent magnet gaps, 9 mm (left) and 20 mm (right), in the elliptical modes.

The K value of an EPU can be controlled without changing the magnet gap by shifting the arrays individually in the longitudinal direction. Figure 5 shows the moving direction of the magnet arrays of APPLE-X for the inclined mode and energy shift mode.

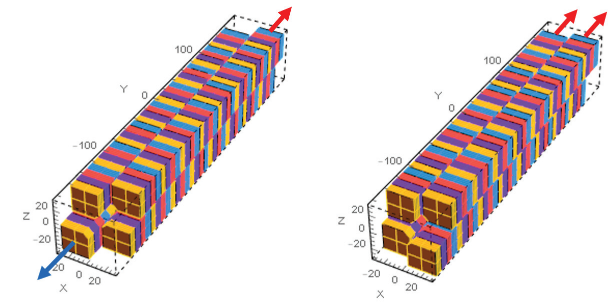

Figure 5: Moving directions of magnet arrays for inclined mode (left) and energy shift mode (right).

Inclined Mode

The phase dependence of K values in the inclined (anti-parallel) modes for two periods, 40 and 35 mm, of APPLE-X and APPLE-II undulator types, at the minimum magnet gaps, are compared in Fig. 6. In the elliptical mode, the K value has a valley when the phase is at 90° in the circular mode.

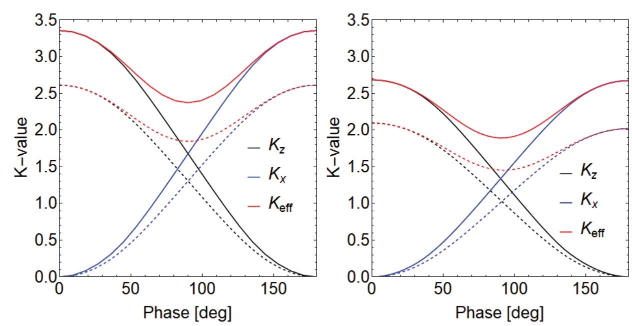

Figure 6: Phase dependence of K values for the cases of 40 mm (solid lines) and 35 mm (dashed lines) periods in the inclined modes. Two undulator types, APPLE-X (left) and APPLE-II (right), are compared.

Energy Shift Mode

The phase dependence of K values in the energy shift modes for two periods, 40 and 35 mm, of APPLE-X and APPLE-II undulator types, at the minimum magnet gaps are compared in Fig. 7. The vertical K (K_z) values not clearly visible in the figure because they are overlapped with the horizontal K.

Gap Change Mode

The K values are effectively controlled by changing the magnet gap. Figure 8 shows the K values variation depending on the magnet gap in the circular modes for both undulator types.

Figure 9 shows the variation in the planar modes. The horizontal and vertical K values of APPLE-X change together because of the geometric symmetry in contrary to APPLE-II as discussed in the previous section.

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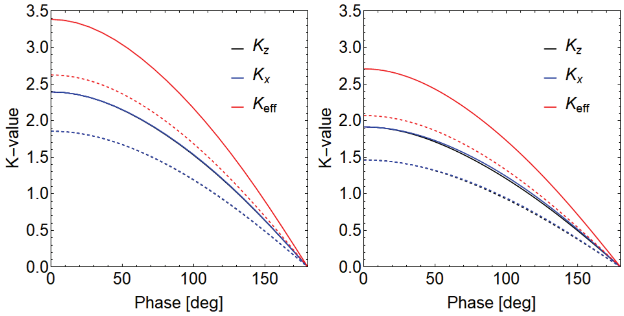

Figure 7: Phase dependence of K values for the cases of 40 mm (solid lines) and 35 mm (dashed lines) periods in the energy shift modes. Two undulator types, APPLE-X (left) and APPLE-II (right), are compared.

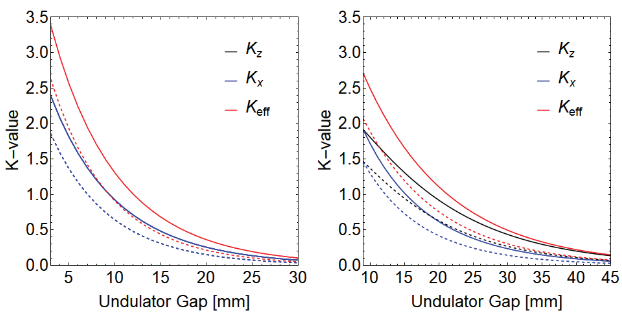

Figure 8: Magnet gap dependence of K values for the cases of 40 mm (solid lines) and 35 mm (dashed lines) periods in the circular modes. Two undulator types, APPLE-X (left) and APPLE-II (right), are compared.

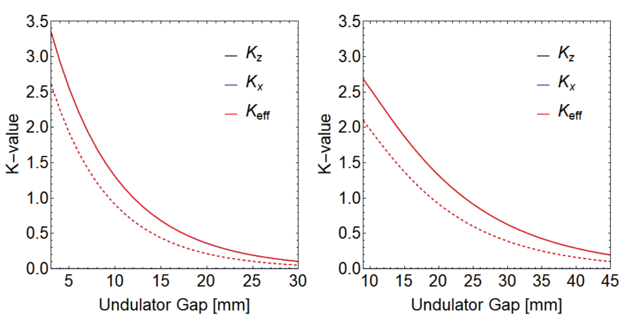

Figure 9: Magnet gap dependence of K values for the cases of 40 mm (solid lines) and 35 mm (dashed lines) periods in the planar modes. Two undulator types, APPLE-X (left) and APPLE-II (right), are compared.

TRANSVERSE GRADIENT OF EPUS

An EPU has a field variation depending on the transverse position except for the planar mode. Figure 10 shows the transverse position dependence of the magnetic field for the energy shift mode and the gap varying mode of APPLE-II. Due to this position dependence, the alignment tolerance of an electron beam to the undulator structure is much tighter than as for a planar undulator.

Such position dependence, or gradient, of K values at the undulator center are plotted in Fig. 11 for the 35 and 40 mm

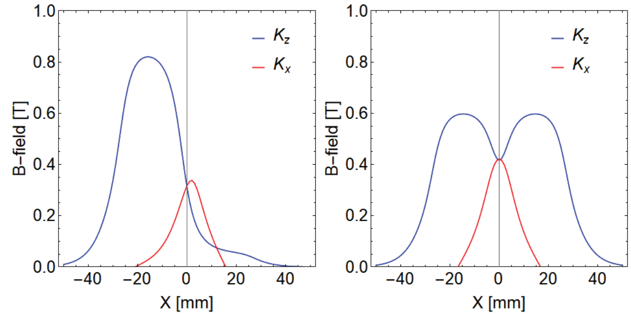

Figure 10: Transverse position dependence of the magnetic field for the energy shift mode (left) and for the gap varying mode (right) of APPLE-II.

periods. APPLE-X provides higher K values with weaker gradients compared with APPLE-II.

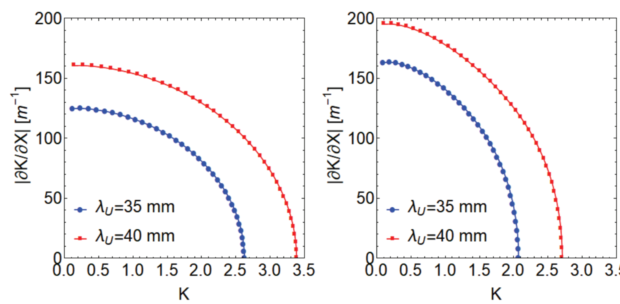

Figure 11: Transverse K gradient in the energy shift modes of the APPLE-X (left) and APPLE-II (right) types.

SUMMARY

Two types of EPUs, APPLE-II, and APPLE-X were compared for the polarization control as after-burner at the PAL-XFEL soft X-ray beamline. To meet the requirements and operational flexibility, a movable gap APPLE-X type undulator with a 40 mm period is thought to be the best candidate in this preliminary study.

ACKNOWLEDGEMENT

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