PERFORMANCE OF APPLE-II TYPE QUASI-PERIODIC UNDULATOR AT HISOR

S. Sasaki, A. Miyamoto, K. Goto, M. Arita, T. Okuda
Hiroshima Synchrotron Radiation Center, Hiroshima University, Higashi-Hiroshima, Japan

Abstract

A 1.8-m-long 78-mm-period quasi-periodic APLPE-II undulator was installed in the 0.7-GeV HiSOR storage ring of Hiroshima Synchrotron Radiation Center. At 23-mm nominal minimum gap, the fundamental photon energies are 3.1 eV, 6.5 eV, and 4.8 eV for horizontal linear, vertical linear, and circular polarization, respectively. The photon energies of observed fundamental and higher harmonic radiations are in good agreement with those of model calculations using measured undulator field and the HiSOR beam parameters. Also, observed flux thorough a slit and a grating monochromator was more than twice larger than that from previously installed 100-mm-period helical undulator for the whole range of radiation spectra.

INTRODUCTION

The Hiroshima Synchrotron Radiation Center of Hiroshima University is a unique synchrotron radiation facility equipped with a small racetrack type storage ring of which nickname is HiSOR. This ring has the electron beam energy of 0.7 GeV, the nominal maximum beam current of 350 mA, and the beam emittance of 400 nmrad. In this ring, two straight sections are capable to install undulators. Each straight section was occupied by a 2.4-m-long 57-mm period linear undulator and 1.8-m long 100-mm period elliptical undulator, respectively. These undulators have been serving high-flux photon beams with energy ranges between five and a few hundred electron-volts for the high-resolution VUV angular-resolved photo-electron spectroscopy experiments. However, due to increasing demands for higher flux and multiple polarizations from HiSOR user community, we decided to renew the elliptical undulator to a shorter period variably polarizing undulator. During the summer shutdown period in 2011, the elliptical undulator was replaced to an APPLE-II type quasi-periodic variably polarizing undulator (QP-APPLE-II) in order to meet higher photon flux requirement for investigating electronic properties of newly found exotic materials such as high-T_c superconductor, topological insulator, etc.

Figure 1 shows the QP-APPLE-II undulator under magnetic measurement before installation to the HiSOR ring. This undulator has 78-mm period length, 1.8-m total length, and the nominal minimum gap of 23-mm. The peak magnetic fields at the minimum gap are 0.85 T for the horizontal linear mode, 0.47 T for circular mode, and 0.57 T for vertical linear mode, respectively. In this paper, after a brief description about the principle of quasi-periodicity, the performance and the effect on stored electron beam of the QP-APPLE-II undulator are presented.

#sasakis@hiroshima-u.ac.jp

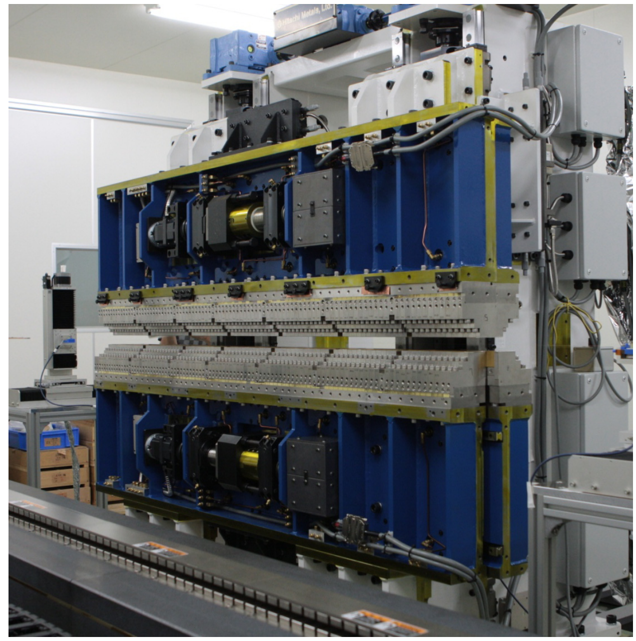

Figure 1: New QP-APPLE-II undulator on the magnetic measurement bench.

QUASI-PERIODICITY AND MAGNETIC FIELD VARIATION

One of the foresighted methods to create the one-dimensional quasi-periodicity is to project 2D rectangular lattice onto an irrationally inclined straight line. This procedure can be transformed into a simple equation as follows.

$$\tilde{z}_m = m + (r\tan\alpha - 1)\left\lfloor \frac{\tan\alpha}{r+\tan\alpha} m + 1 \right\rfloor, \qquad (1)$$

where, $\tilde{z}_m$ represents a normalized coordinate of m-th lattice point on the inclined axis, and the bracket $\lfloor x \rfloor$ stands for the greatest integer less than x. The letter r represents the ratio b/a [1,2].

The coordinate values are proportional to the phase advance of emitted light from the origin of undulator axis, and therefore, the phase advance at m-th pole can be written as:

$$\phi_m = \pi\left\{ m + (r\tan\alpha - 1)\left\lfloor \frac{\tan\alpha}{r+\tan\alpha} m + 1 \right\rfloor \right\}. \qquad (2)$$

Then, the phase advance in each half period is written as:

$$\Delta\phi_m = \phi_{m+1} - \phi_m . \qquad (3)$$

And therefore, the phase steps in a typical half-period interval of periodic section and of quasi-periodic section

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are written as: $\Delta\phi_p = \pi$ and $\Delta\phi_q = \pi r \tan\alpha$, respectively.

In general, the phase function for each period in an undulator is given by the following equation [10]:

$$\phi = \frac{2\pi}{\lambda_{photon}}\left(\frac{z}{2\gamma^2} + \frac{\int x'^2\, dz}{2}\right), \qquad (4)$$

where λ_{photon} is the wavelength of emitted photon and x' is the angle of electron trajectory in an undulator.

After some calculations by assuming the sinusoidal magnetic field in each period, the phase step ratio is found to be nearly equal to the most right side of following equation:

$$\Delta\phi_q / \Delta\phi_p = r\tan\alpha \cong \left(\frac{2B_{0q}{}^2 - B_{0p}{}^2}{B_{0p}{}^2}\right). \qquad (5)$$

It is obvious from Equation (5), the peak magnetic field ratio between the quasi-periodic part and periodic part (B_{0q}/B_{0p}) is uniquely determined by inserting appropriate values into parameters r and tanα. For the HiSOR QP-APPLE-II, we adopted r=1.5 and $\tan\alpha = \sqrt{15}$. Figure 2 shows the partial drawings of 2D rectangular lattice and projected 1D lattice points on the inclined line. In a real undulator, the magnet block(s) at a quasi-periodic part should be retracted so that adjacent peak fields with opposite sign are smaller than those at periodic parts.

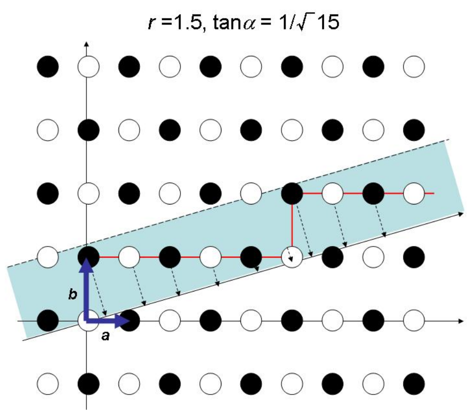

Figure 2: Relation between 2-D rectangular lattice and a 1-D quasi-periodic lattice.

HiSOR APPLE-II UNDULATOR

By using parameters in the previous section for the quasiperiodization of HiSOR QP-APPLE-II undulator, the phase step ratio becomes: $\Delta\phi_q / \Delta\phi_p = r\tan\alpha \approx 0.387$. It gives the peak filed ratio B_q/B_p≈0.83. To realize this ratio and desired quasi-periodicity described by Eq. (2), the magnet block retraction is determined to be 12-mm, and quasi-periodic positions are set at 9th, 16th, 22nd, 29th, 36th, and 43rd horizontally magnetized blocks.

Figure 3 shows an example of RADIA modelling and a calculated field distribution for the circular polarization mode [3].

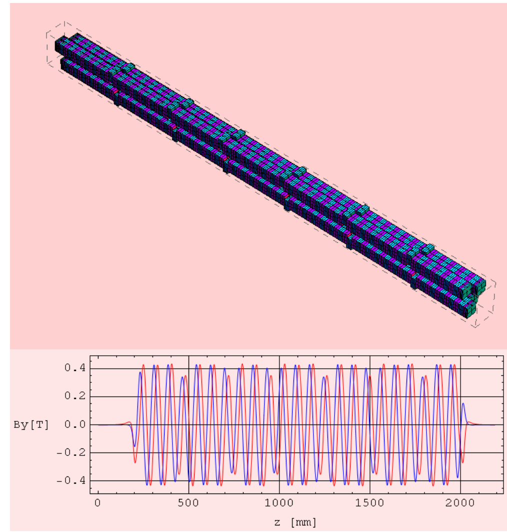

Figure 3: RADIA model of HiSORQP-APPLE-II undulator and its magnetic field distribution (circular polarization).

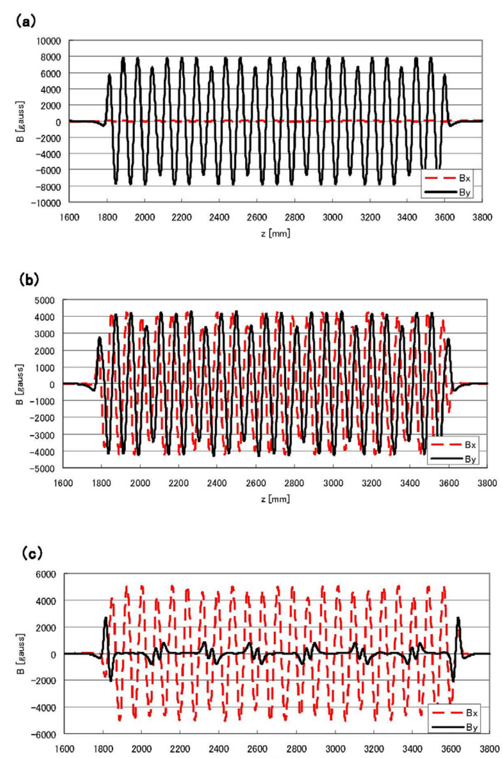

Figure 4: Measured field distributions at 25-mm gap; (a) horizontal, (b) circular, and (c) vertical polarization mode.

Figure 4 shows measured magnetic field distributions at the gap of 25-mm for the horizontal linear, circular, and vertical linear polarization modes. These results are in good agreement with results of model calculation. Radiation spectra calculated by using measured field data and the HiSOR ring parameters are shown in Fig. 5. From these results, it can be clearly seen that the rational harmonics are well suppressed for the horizontal linear and circular polarization modes. However, the third harmonic peak remains for the vertical polarization mode.

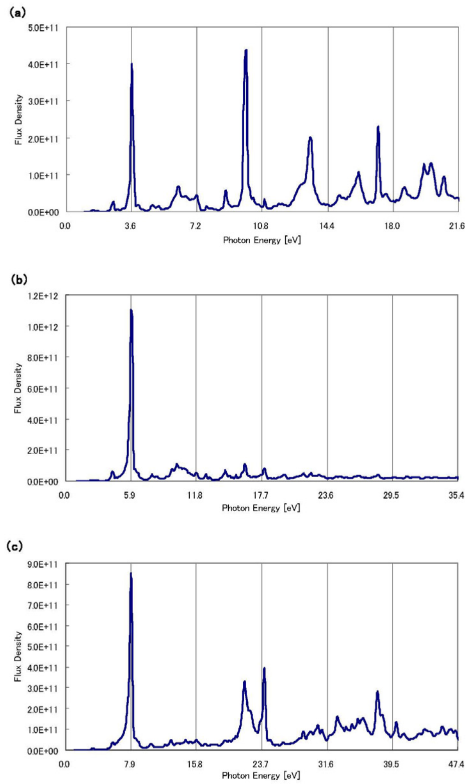

Figure 5: Radiation spectra at 25-mm gap in various polarization mode; (a) horizontal linear, (b) circular, and (c) vertical linear polarization mode.

The contamination of the first harmonic by the rational third harmonic for vertical polarization mode is due to the spread phase step error at quasi-periodic positions caused by the mechanical position shift of magnet rows.

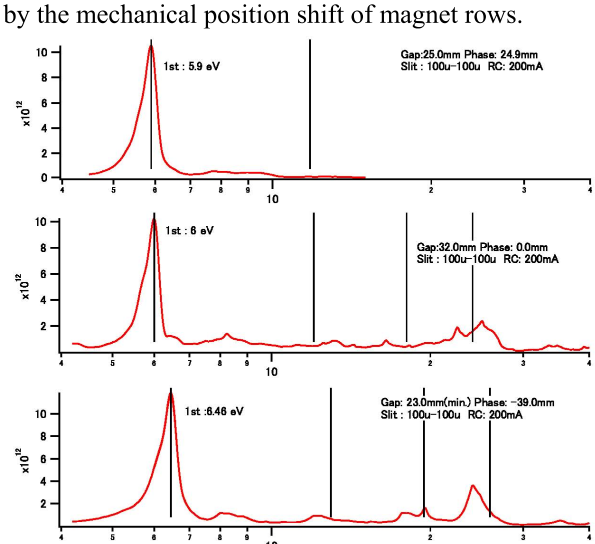

Figure 6: Radiation spectra observed at the end-station of BL-9A; (top) circular, (middle) horizontal, and (bottom) vertical polarization mode.

Figure 6 shows observed radiation spectra at the beamline BL-9A End-Station. In this figure, the top graph represents the spectrum of circularly polarized radiation at 25-mm gap, the middle and the bottom show horizontal linear radiation at 32-mm gap and vertical linear at 23-mm gap, respectively. Solid vertical lines represent positions of 2nd, 3rd, and 4th harmonic, respectively. Figure 7 shows the first light from the QP-APPLE-II undulator captured with a camera.

Figure 7: Observed synchrotron radiation light from the QP-APPLE-II undulator.

In regard to the effect on stored electron beam, the magnet gap and the magnet row phase dependence of beam size was observed as shown in Fig. 8. The maximum variation of beam size is smaller than 10% at the minimum gap, and no impediment of user operation has been reported. However, this level of beam size variation and differences of rational higher harmonic contents may affect the accuracy of users experiments such as the high precision polarization dependent photo-electron spectroscopy and linear magnetic dichroism.

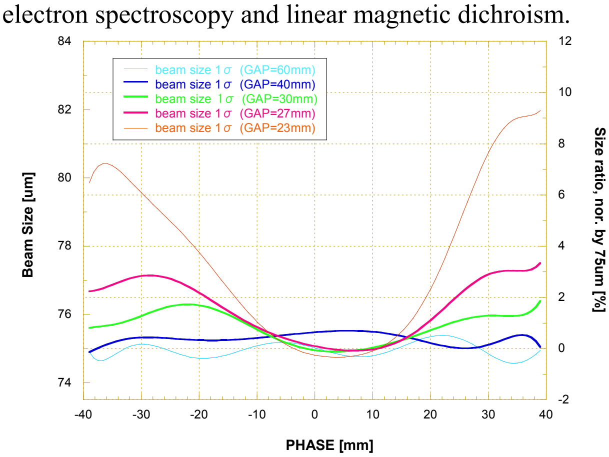

Figure 8: Magnet gap and magnet row phase dependence of stored beam size.

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