Quasi-Periodic Variably Polarizing Undulator at HiSOR

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Abstract. A 1.8-m-long 78-mm-period quasi-periodic APLPE-II undulator was installed in the 700-MeV HiSOR storage ring of Hiroshima Synchrotron Radiation Center. At the minimum gap, achievable lowest photon energies are 3.1 eV, 6.5 eV, and 4.8 eV for horizontal linear, vertical linear, and circular polarization, respectively. Observed photon energies of fundamental and higher harmonic radiations are in good agreement with those of model calculations using measured magnetic field of undulator and the HiSOR beam parameters. Also, observed flux through 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. The feedforward COD correction was done to avoid the intensity fluctuation of photon beam in other beamlines due to the gap and phase motion of undulator. No fatal effect on the stored electron beam by installing the undulator was observed though a slight beam size change was observed at the minimum gap.

1. Introduction

The Hiroshima Synchrotron Radiation Center of Hiroshima University is a synchrotron radiation facility having 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, only two straight sections are capable to install undulators. Each straight section had been 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 had 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 from HiSOR user community for higher flux and multiple polarizations, we decided to renew the old elliptical undulator to a shorter period variably polarizing undulator. During the summer shutdown period in 2011, the elliptical undulator was replaced to a quasi-periodic APPLE-II type variably polarizing undulator (QP-APPLE-II) in order to meet users’ requirement for investigating electronic properties of newly found exotic materials such as high-Tc superconductors, topological insulators, etc.

This new undulator has 78-mm period length, 1.8-m total length, and the 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.

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2. How to create 1-D quasi-periodicity

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.

\[ \tilde{z}_m = m + \frac{r \tan \alpha - 1}{r + \tan \alpha} m + 1. \]  \hspace{1cm} (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:

\[ \phi_m = \pi m + \frac{r \tan \alpha - 1}{r + \tan \alpha} m + 1. \]  \hspace{1cm} (2)

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

\[ \phi = \frac{2\pi}{\lambda_{\text{photon}}} \left( \frac{2}{2\gamma^2} + \frac{\chi^2}{2} dz \right). \]  \hspace{1cm} (4)

where \( \lambda_{\text{photon}} \) 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 written as follows:

\[ \Delta \phi_q / \Delta \phi_p = r \tan \alpha \approx \left( \frac{2 \dot{E}_{0q}^2 - \dot{E}_{0p}^2}{\dot{E}_{0p}^2} \right). \]  \hspace{1cm} (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 once 1D quasi-periodic parameters are selected. For the HiSOR QP-APPLE-II, we adopted \( r=1.5 \) and \( \tan \alpha = \sqrt{3} \). Figure 1 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.
3. HiSOR QP-APPLE undulator

By using parameters of quasi-periodicity in the previous section for the HiSOR QP-APPLE-II undulator, the phase step ratio becomes: \( \frac{\Delta \phi_q}{\Delta \phi_p} = r \tan \alpha \approx 0.387 \). It gives the peak field ratio \( B_q/B_p \approx 0.83 \). 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 9\textsuperscript{th}, 16\textsuperscript{th}, 22\textsuperscript{nd}, 29\textsuperscript{th}, 36\textsuperscript{th}, and 43\textsuperscript{rd} horizontally magnetized blocks.

Figure 2 shows the QP-APPLE-II undulator under magnetic measurement and that installed into the HiSOR ring.
In this figure, missing-teeth-like positions in each magnet array are positions where the quasi-periodicity was introduced [1,2]. Due to an appropriate quasi-periodic magnetic structure and hence the quasi-periodic electron trajectory, every higher harmonic radiation appears at a certain irrational position in the spectrum so that SR users can use highly monochromatic photon beam with smaller contaminations by rational harmonics at their end-station after monochromator.

Figure 3 shows measured magnetic field distributions at the gap of 25-mm for the horizontal linear, circular, and vertical linear polarization modes [3]. These results are in good agreement with results of model calculation (see ref. [3]) with 3D magnetic simulation code RADIA.
Ideally, the quasi-periodicity can be generated in a periodic undulator by introducing the reduced (or increased) peak field of adjacent peak positions with opposite sign each other at quasi-periodic positions. A nearly ideal field distribution is achieved for the vertical magnetic field in the horizontal polarization mode as shown in Fig. 3 (a). However, as one can clearly see in Fig. 3 (c), there exists smeared horizontal magnetic field variation and a finite (non-zero) vertical magnetic field variation in the vertical polarization mode. This unwanted variation is caused by the position error due to a longitudinal shift of magnet row along the undulator axis.

Figure 4 shows radiation spectra calculated by using measured field data and the HiSOR ring parameters and observed radiation spectra at the beamline BL-9A End-Station. From these results, it can be clearly seen that the integer harmonics are well suppressed for the horizontal linear and circular polarization modes. However, the third harmonic peak remains for the vertical polarization mode. On the right column of 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 2nd, 3rd, and 4th harmonic positions, respectively.
In regard to the effect on stored electron beam, small changes of electron beam size were observed depending on magnet gap and the magnet row phase. The maximum variation of beam size was observed to be smaller than 10% for the vertical-linear polarization mode at the minimum gap, and no fatal problem for user operation has been reported. Measured multipole components are smaller than those in required multipole specification (<0.01 T, <2 T/m, <300 T/m² for quadrupole, sextupole, and octupole, respectively), and no effect on e-beam observed.

References
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