Experimental Study of Quasi-periodic Undulator

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1. Introduction

In an electron (or positron) storage ring for synchrotron radiation, an undulator is an insertion device producing high brilliant light with sharply peaked spectrum. An undulator gives rise to periodic magnetic field so that the light wave radiated at each period interferes with each other. The interference strengthens the intensity at a specific wave-length satisfying the phase condition. In other words, the synchrotron radiation from an undulator has a harmonic spectral structure. For the sake of installation convenience, an undulator usually settled in a storage ring possesses planer structure of magnetic poles. An electron passing through a planer undulator moves sinusoidally in the plane perpendicular to the magnetic field. The motion produces the longitudinal oscillation in the electron rest frame on average. The longitudinal periodic motion enhances higher harmonics in radiation spectrum.

In some synchrotron radiation experiments, monochromatic light is preferable for preventing the data signal from contamination of higher harmonics. A way to remove the higher harmonics from the spectrum is to reduce the K-parameter, on which the intensity of higher harmonics depends more strongly and decreases more rapidly than lower harmonics. In case, however, of scanning a wide range in the spectrum, one needs to use higher harmonics or large K, *i.e.* one can not impudently decrease K. Another method to pick out a harmonic from the harmonics is to monochromatize the radiation by means of optics complex. In hard x-ray region, however, the monochromatization by the optics system becomes difficult owing to the small critical angle of total reflection or the narrow Darwin width.

Recently, Hashimoto and Sasaki [1] invented a new undulator, whose radiation spectrum includes no rational harmonics but irrational ones. The magnet poles of the undulator, which will be referred to as quasi-periodic undulator (QPU), constitute a quasi-periodic array so that the radiation from the undulator has irrational harmonic spectrum. After passing through a monochromator, the light radiated from QPU contains no contamination of higher harmonics. In this way, the usage of QPU simplifies the optical components for monochromatization.

Theoretical investigation on QPU was extensively performed in 1994 and the spectral formula of the synchrotron radiation from QPU was derived [2]. In order to prove the practical validity of QPU, we constructed and set up a trial model in the electron storage ring, **NIJI-IV** at ETL, and measured the spectrum.

2. Basic Concept

A basic magnetic structure for the QPU can be realized by aligning positive and negative magnet poles alternately at 1D quasi-lattice points $\hat{z}_m$ given by

$$\hat{z}_m = m + \left(\frac{1}{\tau} - 1\right)\left[\frac{1}{1+\tau}m + 1\right], \qquad (1)$$

where τ is an irrational number. The symbol [] represents the greatest integer operator. Based on the magnetic configuration described by Eq. (1), we can derive an analytical formula giving the peak intensity and the frequency of the radiation spectrum from QPU [2]. For example, the resonant frequency ω_{pq} of the synchrotron radiation from the QPU is represented by

$$\omega_{pq} = \frac{k_{pq}}{\pi}\omega_2. \qquad (2)$$

Here

$$k_{pq} = \begin{cases} \dfrac{2\pi\left(p + q\dfrac{1}{1+\tau}\right)}{\dfrac{1+\tau^2}{1+\tau} - \eta}, & \text{for even mode,} \\ \dfrac{2\pi\left(p + q\dfrac{1}{1+\tau}\right) - \pi}{\dfrac{1+\tau^2}{1+\tau} - \eta}, & \text{for odd mode,} \end{cases} \qquad (3)$$

with p, q some integers, ω_2 the fundamental frequency of the radiation and

$$\eta = \frac{\tau}{2}\frac{K^2}{1 + K^2 + (\gamma\theta_0)^2}. \qquad (4)$$

3. Experiment

The parameters of the ring and the model QPU are listed in Table 1. We measured the spectra of the radiation on axis at several undulator gap and of the off-axis

Table 1. Parameters of **NIJI-IV** and QPU

electron beam current	1.95 – 8.44 mA
electron beam energy	187.3 MeV
quasi-periods	25 mm / 55.9 mm $(1/\sqrt{5})$
number of poles	27
peak magnetic field (gap = 36 mm)	0.24 T

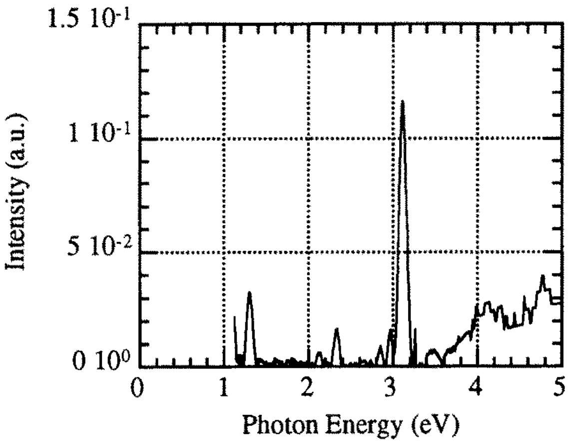

Fig. 1. Measured spectrum with undulator gap 38 mm.

radiation at several angles. The measured on-axis radiation spectrum from QPU at gap 38 mm is shown in Fig. 1. As expected, there is no rational relation among the harmonics. The slopes of the radiation around low and high ends are noises of detection. This can be convinced by the fact that the intensity slopes do not move as we change the undulator gap, while the peaks shift. The calculated spectrum is shown in Fig. 2. The resonant energies of both of the spectra are listed in Table 2. In Table 2 (or Fig. 2), the absence of the second mode in calculated spectrum originates in the fact that the calculation was performed with zero emittance of electron beam. Except for scale error about 5 %, the peak positions of both spectra agree with each other. The investigation of the off-axis radiation spectrum implies that the second mode in Fig. 1 is even. Figure 3 shows the radiation spectrum at undulator gap 38 mm and 0.6 mrad off-

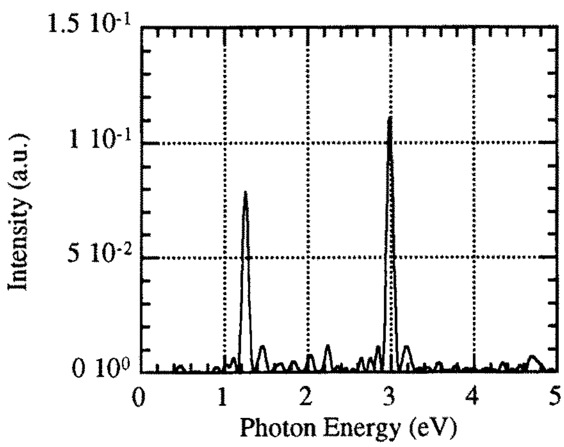

Fig. 2.: Calculated spectrum with undulator gap 38 mm.

Table 2. Peak energies of QPU radiation spectrum.

mode (p, q)	measured (eV)	calculated (eV)
odd (0,1)	1.305	1.25
even (0,1)	2.340	-
odd (2,-1)	3.116	2.99

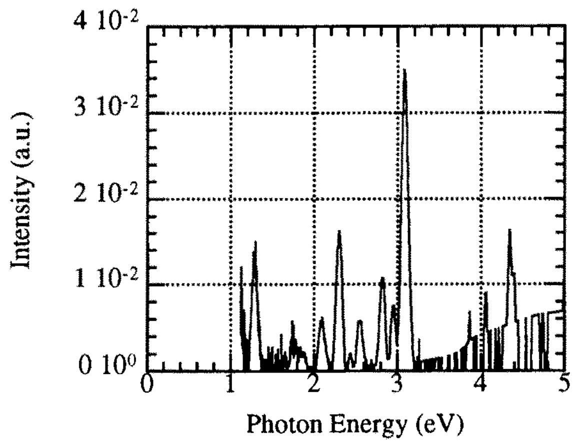

Fig. 3. Measured spectrum at 0.6 mrad off-axis.

axis. The second mode in the off-axis spectrum is relatively enhanced in comparison with in the on-axis one.

In conclusion, QPU can thoroughly reduce rational higher harmonics which can not be removed by a simple monochromator.

References

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