FIRST OBSERVATION OF QUASIPERIODIC UNDULATOR RADIATION

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Abstract

A test quasi-periodic undulator(QPU)1.245m long was constructed and installed in a compact storage ring NIJI-IV to confirm the validity of the prediction of a new concept of quasi-periodic undulator. We have observed, for the first time, the radiation spectrum composed of harmonics with irrational ratio, which is quite different from the harmonic spectrum with rational ratio common in conventional undulators. The spectrum agrees with the theoretical prediction . The storage ring was operated about 190 MeV to provide the spectrum in the region of near infrared to ultraviolet wavelength, and the spectrum was observed with a grating monochromator.

1 INTRODUCTION

Recently, a new concept of quasi periodic undulator (QPU) was proposed [1,2], and we have constructed a short QPU to check the performance of the undulator. In the accompany papers, the design [3] and construction and field measurements of the undulator [4] are presented. The QPU generates the radiation spectrum composed of harmonics with irrational ratio, which is quite different from the harmonic spectrum with rational ratio common in conventional undulators. Conventional undulators have periodic magnetic structures. This leads to a generation of rational harmonics of radiation such as the third and fifth harmonics in addition to the fundamental radiation unless the deflection parameter K is very small. In case of user's experiments, the mixing of higher harmonics is not welcome because it leads to a degradation of the signal-to-noise-ratio. The higher harmonics of radiation are usually removed by using a total reflection mirror which reflects below the critical energy at a given reflection angle. However, these conventional techniques are somewhat difficult to use or useless in the hard x-ray region.

Recently, in order to avoid the higher harmonic contamination, we propose a new type of undulator which never generates the rational higher harmonics but generates the irrational ones.

This undulator was installed in the compact storage ring NIJI-IV[5,6], and the first in-beam experiment has been done successfully. The parameters of QPU undulator were optimized for output in the visible light region at an electron energy of around 190 MeV so as to examine the performance of this device in the simplest way.

2 UNDULATOR AND MACHINE PARAMETERS

The basic structure of the QPU is plain parallel and pure permanent magnet type undulator with mechanism of the gap adjustable. However the QPU has quasi-periodic magnetic field, produced by the quasiperiodic magnetic structure shown in Figure 1. The manner of arraying the magnets in the quasiperiodic undulator is determined in the way of the Fibonacci sequence with two irrationally different interpole distances. The arrow in each magnet block represents the magnetization direction. The isolated magnet blocks are thinner by a factor of 0.7 in order to reduce the strength of the on-axis magnetic field to the same order of contribution from the other nonisolated magnets. In this experiment, we chose an irrational number $\eta = \sqrt{5}$ consequently $d'/d = \sqrt{5}$. The interpole distances d and d' are 25 and 55.9 mm, respectively. The salient parameters are given in Table 1.

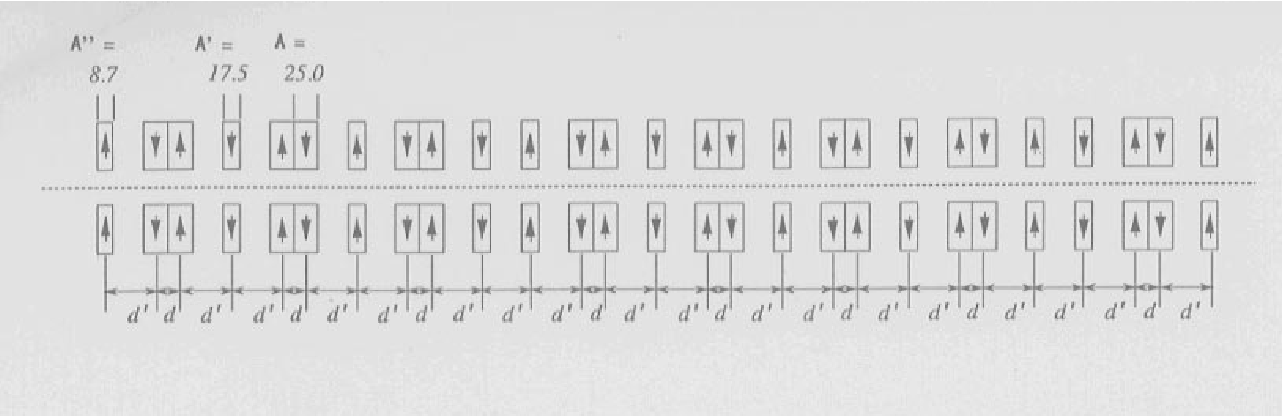

Figure 1: Magnetic structure of the quasiperiodic undulator.

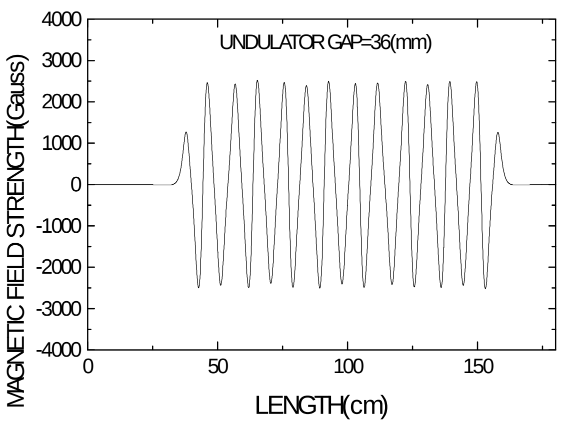

Figure 2: Spatial distribution of magnetic field of the QPU.

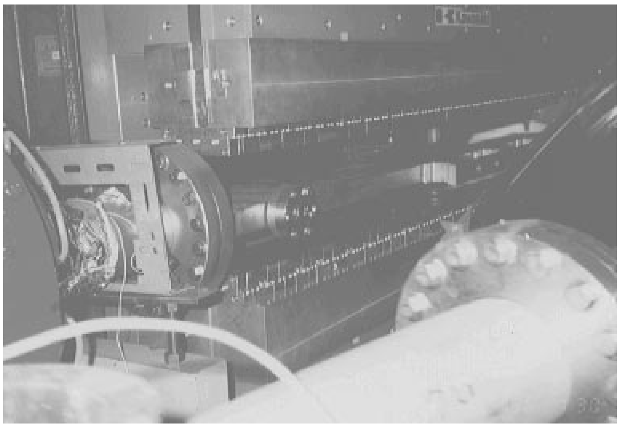
Figure 3: Photograph of the QPU installed in the NIJI-IV

Figure 2 shows the variations of magnetic field along the undulator axis at the gap of 36 mm. The magnetic field was measured by a Hall-effect probe.

The storage ring NIJI-IV, used in this experiment, has the triple bend achromatic lattice with superperiodicity of 2. It has two long straight sections. One straight section is dedicated to the optical klystron for FEL installation and the others is used for the QPU. Figure 3 shows the photograph of the QPU installed in the NIJI-IV. The major parameters of NIJI-IV are listed in Table 2 . The betatron tune and the natural emittance are ν_x=2.230 and ν_y = 1.355, and 4.913×10^{-8} m rad, respectively.

3 IN-BEAM EXPERIMENTS

Direct visual observation of the radiation produced by the QPU was made at about 15 m from the source point (center of the QPU). Most of the central part of the output SR light is introduced in the presence of air to a monochromator combined with a highly sensitive photodiode. The spectral resolution is 0.2 nm. The undulator has been operated for output in the visible light region at an electron energy of around 190 MeV so as to examine the performance of this device in the simplest way. The electron beam and the center line of the undulator were aligned precisely on the same axis. Figure 4 shows the output spectrum obtained with the monochromator for an undulator gap width of 40 mm and an electron energy of 187.3 MeV. The stored electron beam current was 3 mA with full bunched beam operation. The first peak wavelength and the bandwidth read from the spectrum in Fig. 4 are 363 nm and 12.19 nm, respectively. And the second peak wavelength and the bandwidth are 874 nm and 77.9 nm, respectively. As can clearly be seen in this figure, no rational harmonics are observed. In this experiment, the rational spectrum such as the third harmonics is 291 nm by assuming the peak of longest wavelength as the fundamental. However, the corresponding to the third harmonics of the spectrum was not observed.

The theoretical prediction of the fundamental and the next peak wavelength generated from the QPU are 911 nm and 381 nm, respectively. And the theoretical spectrum width of these peaks are 80 nm and 14 nm, respectively. Hence, the measured spectrum of the QPU agrees with the theoretical prediction, while both peaks are shifted by 5%.

Table 1: Undulator design parameters

Type	pure permanent magnet
Structure	plain parallel
Inter-pole distances	25(*d*)+55.9(*d'*)
Magnet length	A=25 mm
	A'= 17.5 mm
	A'' = 8.7 mm
Number of period	13
Total length	1245 mm
Peak magnetic field	>0.22 T
Magnet material	N36H(Br>12.0kG)
Magnet block width	80 mm
Magnet block height	35 mm
Minimum gap	36 mm
First integration of magnetic field	$<10^{-3}$ T-m

Table 2 :Parameters of NIJI-IV

Injection beam energy	300 MeV
Stored beam energy	500 MeV (max.)
Circumference	29.6 m
Bending radius	1.2 m
Betatron tune ν_x	2.230
ν_y	1.355
Momentum compaction factor	0.088
Natural emittance	4.913×10^{-8} m rad
Relative energy spread	2.28×10^{-4}
RF frequency	162.14 MHz

4 SUMMARY

We have constructed and installed quasi-periodic undulator in a compact storage ring NIJI-IV to confirm the validity of the prediction of the new concept. We have observed, for the first time the radiation spectra from the quasi periodic undulator for the case of $\eta=\sqrt{5}$. The measured radiation from this device has no rational harmonics but irrational ones with no drastic decrement of radiation peaks.

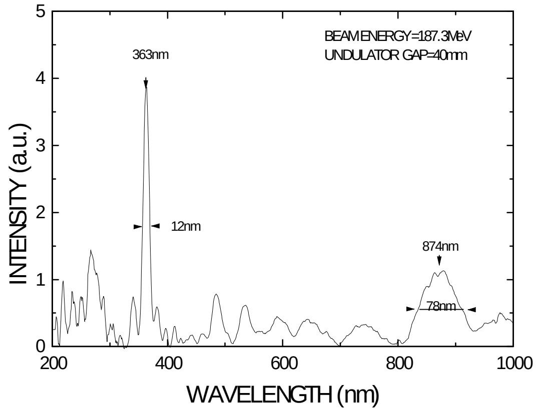

Figure 4: Measured spectrum of power density from the quasiperiodic undulator.

The quasiperiodic undulator will give an opportunity to explore a new horizon in the field of synchrotron radiation research by offering brilliant photon beams with unique spectral properties which have never been observed before.

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