DESIGN OF AN ELLIPTICAL UNDULATOR AND X-RAY BEAM LINE AT DSR OF RIKEN RI BEAM FACTORY PROJECT

M. Wakasugi and T. Katayama*

RIKEN, The Institute of Physical and Chemical Research, Wako, Saitama 351-01, Japan
*Center for Nuclear Study, School of Science, University of Tokyo, Tanashi, Tokyo 188, Japan

Abstract

According to requirements from the X-ray - RI collision experiment at DSR that is proposed in the RIKEN RI beam factory project, an undulator for elliptically polarized X ray was designed. An Apple-II type of the undulator was adopted so that both the X-ray energy and the polarization are continuously changed at the same time. The photon flux of more than 10^{15} photons/s/0.1%b.w. is calculated for any polarization in the energy range of 30 - 800 eV.

1 INTRODUCTION

The X-ray - RI collision experiment proposed in the RIKEN RI beam factory project [1,2] requires on the X ray as follows. The X-ray energy is 30 -800 eV and it can be continuously scanned with the step of less than 0.1 eV. Any polarization of the X ray can be chosen. The polarization should be kept during the energy scanning. The X-ray beam intensity is as large as possible, and the energy resolution is also as high as possible.

For the experiment, the higher energy resolution is essential because the isotope shifts in the X-ray transitions of the Li-like RI ion beam have to be resolved [3]. Since the resolution of the X ray from the undulator is not enough, the X-ray spectrometer having high energy resolution of about $\Delta E_e/E_e = 10^{-4}$ should be used. The X-ray beam line including the X-ray spectrometer is inserted between the undulator and the X-ray - RI colliding section. To get the X ray beam intensity of more than 10^{12} photons/s/0.01%b.w. at the colliding section, output photon flux from the undulator has to be more than 10^{15} photons/s/0.1%b.w.

In this paper, the design of the magnetic structure, calculated X-ray spectra and the mechanical design of the undulator for elliptically polarized X ray are reported.

2 SPECIFICATIONS OF ELECTRON BEAM IN DSR

The intensity and the polarization of photon beam strongly depend on the electron beam quality in the DSR. To make low emittance electron beam, DBA lattice is adopted in the arc section of the DSR [4]. As described in Ref. [3], the electron beam having the energy of 0.3 - 2.5 GeV is stored in the DSR. The calculated electron beam specifications are listed in Table 1. The averaged current is 0.5 A. The beam emittance is obtained to be $\varepsilon_x/\varepsilon_y$ = 7.8/13.9 nmrad at the maximum energy of 2.5 GeV. Since the beta function value at the undulator section is about 5 m, the electron beam size at the undulator section is smaller than σ_x/σ_y = 197/264 μm.

3 DESIGN OF APPLE-II TYPE UNDULATOR

3.1 Magnetic Structure

Figure 1 shows the schematic view of the magnetic structure of the Apple-II type of the undulator proposed by Sasaki et al. [5]. This has two pairs of planer permanent magnet (Nd-Fe-B) arrays above and below the electron beam plane. The X-ray energy is scanned by changing the gap width. The polarization is changed by shifting the relative position of pairs of magnetic arrays. On-axis magnetic field produced by the phase shifting makes helical and sinusoidal motions of the electron beam. The magnetic field in horizontal and vertical directions are shown in Fig. 2 at three different phases. The linear polarization in horizontal and vertical directions are obtained at the phase shifts D = 0 and D = $1/2\lambda_u$, respectively, where λ_u is the length of a magnetic period. the circularly polarized X ray can be get at D = 3/8 λ_u as shown in the figure.

Table 1. The specification of the electron beam in the DSR.

Electron Beam Energy	E_e	(GeV)	0.3	1	1.5	2	2.5
Radiation Loss	U	(keV/turn)	0.1	10.6	53.2	169.1	412.7
Emittance	ε_x	(n m rad)	0.11	1.24	2.8	4.97	7.76
	ε_v	(n m rad)	0.2	2.22	5.01	8.92	13.9
Energy Resolution	$\Delta E_e/E_e$	(10^{-4})	0.82	2.7	4.1	5.5	6.9
Bunch Length	σ_z	(cm)	0.006	0.033	0.061	0.095	0.134
Damping Time	τ_x	(sec)	6.2	0.17	0.05	0.02	0.01
	τ_v	(sec)	6.1	0.17	0.05	0.02	0.01
	τ_e	(sec)	3.1	0.17	0.03	0.01	0.005
Toushek Lifetime	τ	(10^6sec)	0.008	0.16	8.1	180	2.7

0-7803-4376-X/98/$10.00 © 1998 IEEE

3.2 *Minimum Gap and Length of a Period*

The minimum gap width depends on the size of the vacuum tube inserted in the gap. Taking the vertical tube size of 10 mm, the 2-mmx2 tube thickness and the 3-mm x2 spacing between the tube and magnet, the minimum gap width was decided to be 20 mm.

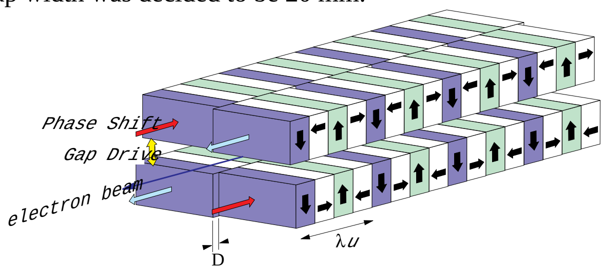

Fig. 1. Magnetic structure of the Apple-II type undulator.

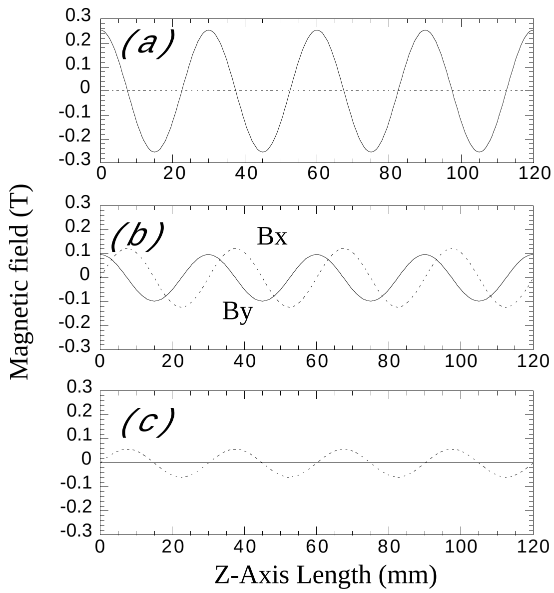

Fig. 2. Magnetic field on the electron beam axis. (a), (b) and (c) correspond to the phase shifts of 0 mm, 11.25 mm and 15 mm, respectively.

When the length of period is decided, the followings have to be considered. The whole system of the undulator is inserted in the limited space of 6.7-m length. The photon flux of more than 10^{15} photons/s/0.1%b.w. has to be obtained using the electron beam having the energy of more than 0.3 GeV and the gap width of more than 20 mm over the X-ray energy range of 30 - 800 eV. Thus the length of the period was decided to be 3 cm. In this case, the maximum K value is 0.712 by assuming the magnetic field strength of 1.3 T at the pole tip of the Nd-Fe-B magnet. The X ray having the energy of 30 - 800 eV can be produced by changing the gap width from 20 to 26.7 mm and the electron beam energy of 0.3 - 1.7 GeV.

3.3 *Magnetic Field along the Beam Axis*

The calculated magnetic fields are shown in Fig. 2, and the relations between the gap width, the phase shift and the maximum field are shown in Fig. 3. The maximum magnetic field is 0.245 T. For any gap width, the circularly polarized X ray is obtained at the phase shift is around 11 mm. To keep the circular polarization during the energy scanning, both the gap width and the phase have to be simultaneously changed along the arrow in the figure.

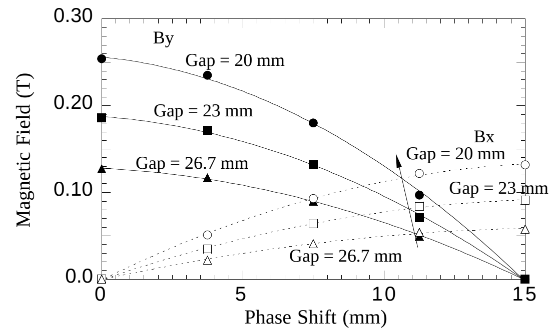

Fig. 3. Maximum magnetic field as a function of the phase shift.

3.4 *Photon Flux*

The photon flux is calculated for both case of the linear polarization (K=0.712) and the circular polarization (K_x=K_y=0.328), and they are shown in Fig. 4. The fluxes are larger than 10^{15} photons/s/0.1%b.w. for both cases in the whole energy range. The requirement from the experiment will be completely satisfied. The flux for the case of the linear polarization is about three times larger than that for circular polarization because of larger magnetic field.

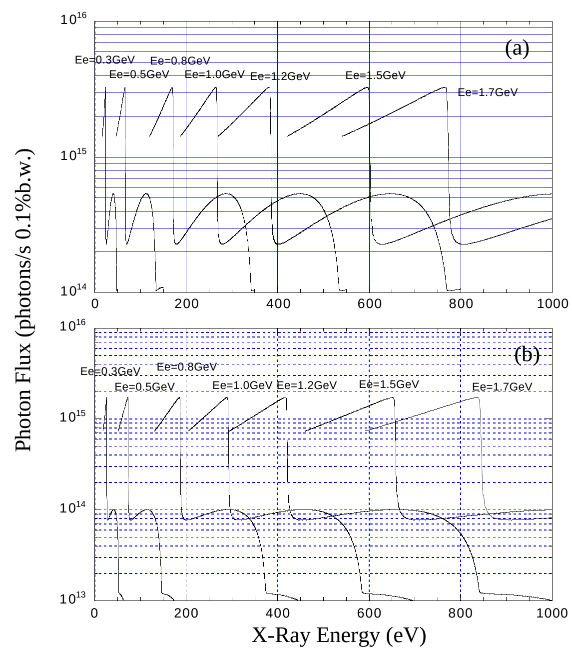

Fig. 4. Photon flux for the linearly polarized X ray (a) and the circularly polarized X ray (b).

4 MECHANICAL DESIGN

4.1 Mechanical Structure

Whole system of the undulator having the total length of 6.24 m is divided into two undulator units because it is too long to construct a 6-m undulator with high accuracy. Both are exactly the same and they are coupled at a distance of 60 mm. The undulator unit consists of the magnet array, array holders, support stands, a vacuum tube, correction magnets, valves, and gap and phase driving system. In one unit, the length of the magnet array is 2400 mm and the number of periods is 80. Total weight is about 7.5 t per unit.

4.2 Vacuum Tube

The vacuum tube inserted in between the magnets has special form because not only the low emittance electron beam but also the heavy ion beam are stored in the DSR depending on the operation mode [4]. The tube has three rooms; those are for the low emittance electron beam, for the heavy ion beam and for the NEG pump as shown in Fig. 5. When the DSR is used as the heavy ion storage ring, the tube is moved without breaking vacuum after expanding the gap width to 300 mm.

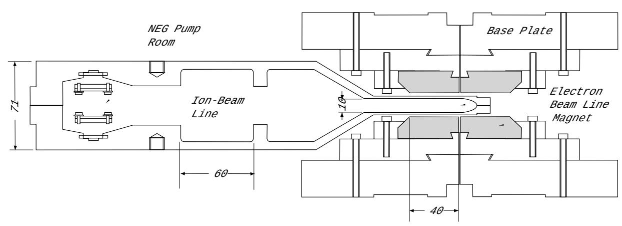

Fig. 5. Cross section of the vacuum tube inserted in between the magnets.

4.3 Gap and Phase Driver

The gap driving system consists of a servomotor, two decelerator, a gear box, four linear guide, position sensors and interlock system. The magnetic force acting on a magnet array is calculated to be about 1 t in the horizontal direction, 0.2 t in the vertical direction and 0.8 t in the beam direction. The accuracy of the gap driving can be achieved to be less than 5 μm that comes from the requirement of the minimum X-ray energy scanning step of 0.1 eV. The driving system has a feed back system from the position sensors, and it can keep the gap width within 3 μm. The phase driver has the same kind of the system.

4.4 X-ray Beam Line

The X-ray beam line including the X-ray spectrometer will be inserted in between the vertically bending magnets at the merging section of the DSR [4]. The design of the spectrometer, which is based on the constant-length spherical grating (CSG) type, is now in progress.

REFERENCES

[1] Y. Yano et al., Proc. 5th European Particle Accelerator Conf., p. 536 (1996).
[2] T. Katayama et al., Proc. 5th European Particle Accelerator Conf., p. 563 (1996).
[3] M. Wakasugi et al., Proc. 5th European Particle Accelerator Conf., p. 611 (1996).
[4] N. Inabe et al., Proc. 5th European Particle Accelerator Conf., p. 926 (1996).
[5] S. Sasaki et al., Nucl. Instrum. Meth. **A331**, 763 (1993).