J. Synchrotron Rad. (1998). **5**, 412–413

In-vacuum figure-8 undulator for hard X-rays with both horizontal and vertical polarization

Takashi Tanaka,* Xavier-Marie Maréchal, Toru Hara, Toshiya Tanabe and Hideo Kitamura

SPring-8, Kamigori-cho, Hyogo 678-12, Japan. E-mail: ztanaka@spring8.or.jp

(*Received 4 August 1997; accepted 15 October 1997*)

A figure-8 undulator of the in-vacuum type has been adopted as an insertion device for BL24XU, the Hyogo Beamline at SPring-8, to provide hard X-rays with both horizontal and vertical polarization instead of a tandem undulator consisting of horizontal and vertical undulators. The undulator will be operated with the gap almost fixed at 11.6 mm to provide the fundamental radiation with horizontal polarization at 9.5 keV and the 1.5th harmonic with vertical polarization at 14 keV.

Keywords: undulators; horizontal and vertical polarization.

1. Introduction

At the Hyogo beamline at SPring-8, a hard X-ray beam that is both horizontally and vertically polarized is necessary for experimental work. The simplest method of providing both horizontal and vertical polarization is to place horizontal and vertical undulators in tandem. In this case, however, the total length of each undulator is necessarily short, resulting in low brilliance.

Another method is to adopt a figure-8 undulator. The figure-8 undulator is an insertion device (ID) proposed at SPring-8 to provide linearly polarized soft X-rays and has the advantage that the on-axis power density is much lower than that of an ordinary linear undulator while the flux density is almost comparable (Tanaka & Kitamura, 1995). Another feature of the figure-8 undulator is that not only integer harmonics but half-odd-integer harmonics appear in the spectrum and have horizontal and vertical polarization, respectively. Using the figure-8 undulator, the total length of the straight section for an ID in the storage ring can be occupied by a single ID; the brilliance is therefore expected to be much higher than that of the tandem type.

In this paper, specifications of the in-vacuum figure-8 undulator for BL24XU are described and calculated results for the magnetic and radiation performance are presented.

Table 1
Specifications of the in-vacuum figure-8 undulator for BL24XU at SPring-8.

Asterisks denote values that are expected to be achieved in future.

Permanent magnet	Nd–Fe–B
Remanent field	1.15 T
Periodic length	26 mm
Number of periods	172
Length of ID	4.5 m
Minimum gap	8 (5*) mm
Maximum gap	50 mm
Maximum vertical field	0.728 (1.050*) T
Maximum horizontal field	0.310 (0.344*) T
Maximum K_y value	1.77 (2.55*)
Maximum K_x value	1.50 (1.67*)
Maximum total power	11.3 (22.0*) kW
Available energy (fundamental)	6.3 (4.1*)–20 keV
Polarization	Horizontal and vertical
Type of device	In-vacuum figure-8

2. Specifications

In order to provide hard X-rays, the periodic length of the undulator should be short. Therefore, an in-vacuum type is adopted. Table 1 and Fig. 1 show the specifications and a schematic illustration of the in-vacuum figure-8 undulator for BL24XU. Inside this device the electron moves along a trajectory which looks like a figure 8 when projected on the transverse plane (Tanaka & Kitamura, 1995). The minimum gap at first is 8 mm; however, it can easily get down to 5 mm with monitoring of the storage ring status such as the vacuum, the beam lifetime and the temperature of the front-end components.

The maximum total power of 22 kW is the highest for any ID that has been constructed or planned at SPring-8. In addition, the spatial distribution of the power density from the figure-8 undulator is asymmetric; therefore, the design and construction of the front-end components should be performed carefully.

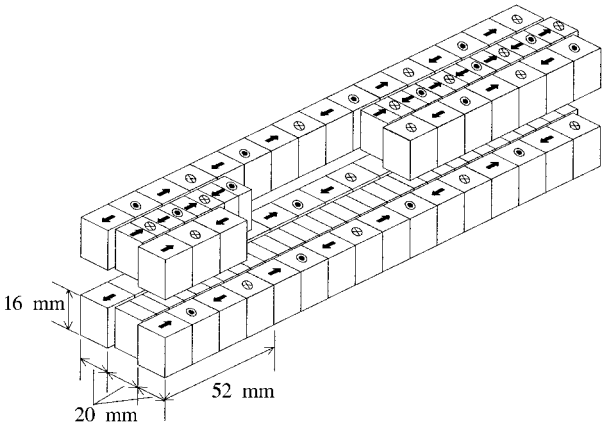

Figure 1
Schematic illustration of the figure-8 undulator for BL24XU.

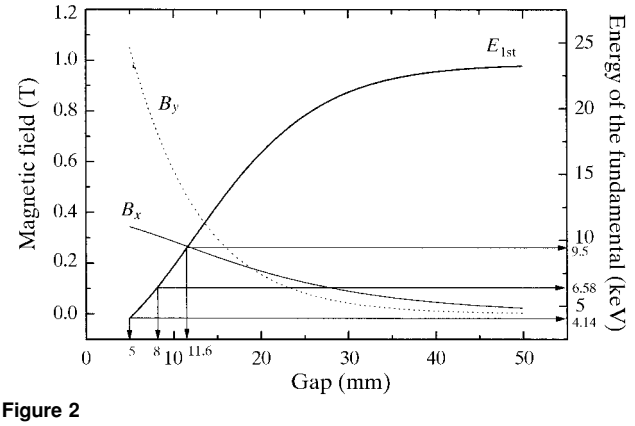

Figure 2
Gap dependence of the horizontal and vertical fields and the energy of the fundamental.

© 1998 International Union of Crystallography
Printed in Great Britain – all rights reserved

3. Calculated performance

In this section, the calculated performance of the in-vacuum figure-8 undulator is described.

Fig. 2 shows the gap dependence of the horizontal and vertical fields and the energy of the fundamental. Although the fundamental radiation can cover the range 4.1–20 keV by changing the gap from 5 to 30 mm, the gap will be almost fixed at 11.6 mm to provide fundamental radiation with horizontal polarization at 9.5 keV and the 1.5th harmonic with vertical polarization at 14 keV.

Fig. 3 shows the spectrum and the degree of linear polarization obtained from the figure-8 undulator for BL24XU at the gap of 11.6 mm. The storage-ring parameters used in the calculation are shown in Table 2. A degree of linear polarization of 1.0 represents complete horizontal polarization and −1.0 represents complete vertical polarization.

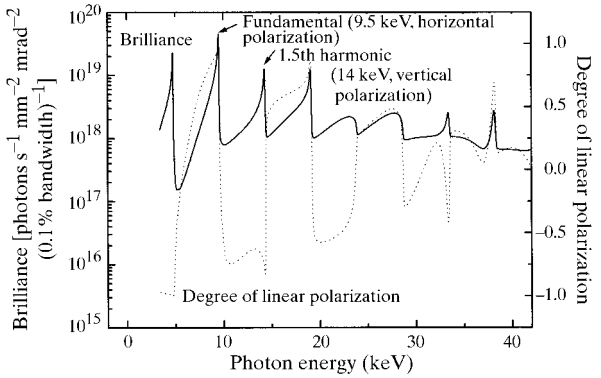

Figure 3
Spectrum and degree of polarization at the gap of 11.6 mm.

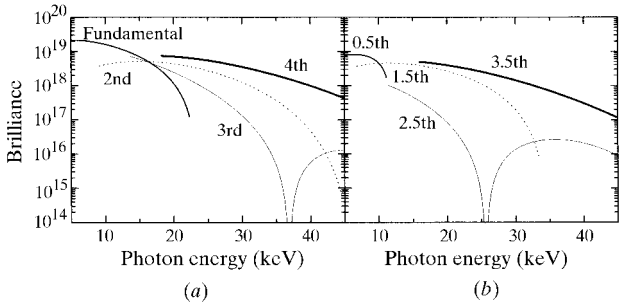

Figure 4
Peak brilliances for harmonics of (*a*) horizontal and (*b*) vertical polarizations as functions of the energy of each harmonic.

Table 2
Storage-ring parameters used for the calculation.

Electron energy	8 GeV
Average current	100 mA
Natural emittance	6 nm rad
Coupling constant	0.02
β_x	1 m
β_y	5 m

The fundamental radiation can be seen at 9.5 keV and the 1.5th harmonic at 14 keV. The degree of polarization is found to be 0.95 at 9.5 keV and −0.80 at 14 keV, meaning that the fundamental has 95% horizontal polarization and the 1.5th harmonic has 80% vertical polarization. Because the degree of polarization obtained from the figure-8 undulator degrades with increase in the vertical observation angle (Tanaka & Kitamura, 1996), the value of the degree of polarization will be improved with reduction in the coupling constant.

Figs. 4(*a*) and 4(*b*) show the peak brilliances for harmonics of the horizontal and vertical polarization as functions of the photon energy of each harmonic. Among these harmonics, the third and 2.5th harmonics cannot be used because their intensity is much lower than that of other harmonics. Nevertheless, using these harmonics properly, both horizontally and vertically polarized photons are available up to 40 keV or higher.

4. Conclusions

The in-vacuum figure-8 undulator for BL24XU has been delivered to the SPring-8 site and field measurements and corrections are now in progress. Since the undulator is of the in-vacuum type, the correction is performed by means of inserting chip magnets into holes in the magnet holder instead of shimming, to keep the magnet surface smooth and avoid the wake field.

As described in §2, the maximum total power of 22 kW is a very high value for the front-end components, and it may therefore be the vacuum or the temperature of the front-end components rather than the beam lifetime that determines the minimum operation gap.

References

Tanaka, T. & Kitamura, H. (1995). *Nucl. Instrum. Methods*, A**364**, 368–373.
Tanaka, T. & Kitamura, H. (1996). *J. Synchrotron Rad.* **3**, 47–52.