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Construction of a vertical undulator at SPring-8

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A new-type insertion device (ID) has been constructed for the structural-biology beamline (BL45XU) at SPring-8. The ID consists of two undulators which can provide vertical polarized radiation (vertical undulators). By changing the individual gap of each undulator independently, photons with two different energies can be obtained. Magnetic field measurements show that the maximum horizontal field is 0.49 T and the magnetic performance is as good as expected.

Keywords: tandem undulators; vertical polarization.

1. Introduction

At the structural-biology beamline (BL45XU) in SPring-8, synchrotron radiation from an insertion device (ID) should be vertically polarized because of the arrangement of the beamline components (Yamamoto *et al.*, 1995).

In order to obtain vertically polarized radiation, the ID (vertical undulator) should have a horizontal magnetic field. The simplest method of generating a horizontal field is to rotate the ordinary planar undulator by 90° along the z axis; however, this is not compatible with installation in the storage ring because the horizontal aperture of the vacuum chamber should be sufficiently large for the injection and the lifetime of the electron beam. Therefore, a planar structure that contains magnet blocks only below and above the orbital plane has been adopted.

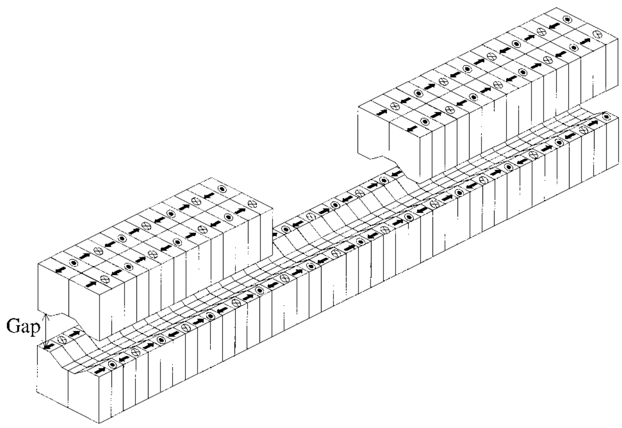

Figure 1
Schematic illustration of a vertical undulator of the SPring-8 type. The gutter in the center is to improve the horizontal uniformity of the magnetic field.

Table 1
Specifications of the ID for BL45XU.

Permanent magnet	Nd–Fe–B
Remanent field	1.15 T
Periodic length	37 mm
Number of periods	37 × 2
Length of ID space	1.5 m × 2
Minimum gap	8 mm
Maximum gap	50 mm
Polarization	Vertical
Type of device	In-vacuum vertical, tandem

As is easily understood, it is difficult to obtain a sufficiently high field with a planar structure if the periodic length is short and/or the magnet gap is large. At SPring-8, an in-vacuum-type ID, first proposed and constructed at the National Laboratory for High Energy Physics, KEK (Yamamoto *et al.*, 1992), is used to overcome this difficulty.

At BL45XU, the photon beam from the ID is split by the first monochromator, called a beamsplitter, and transported into two experimental stations (Yamamoto *et al.*, 1995). The ID for BL45XU consists of two serial vertical undulators placed in a single straight section (a tandem undulator); the undulators can be operated independently. Therefore, users in two different experimental stations can tune the photon energy independently.

2. Specification

Table 1 shows the specifications of the ID for BL45XU (ID45). The number of periods (37 × 2) means that the two undulators are placed in tandem. The standard ID at SPring-8 is 4.5 m long and consists of three standardized units of length 1.5 m. ID45 consists of two standardized units.

Fig. 1 shows a schematic illustration of the vertical undulator for ID45. The gutter in the center is to improve the uniformity of the magnetic field. In addition, the gutter has another advantage. Because ID45 is an in-vacuum undulator, the actual vertical aperture is larger than the magnet gap, meaning that the beam lifetime is longer. In other words, the minimum gap can be reduced without sacrificing the beam lifetime. Although the minimum gap is 8 mm at present, it can be reduced if users need photons with lower energy.

3. Magnetic performance

The magnetic field was measured with a Hall probe, placed in a copper holder whose temperature was controlled with an accuracy of ±0.01 K. The field was corrected by inserting chip

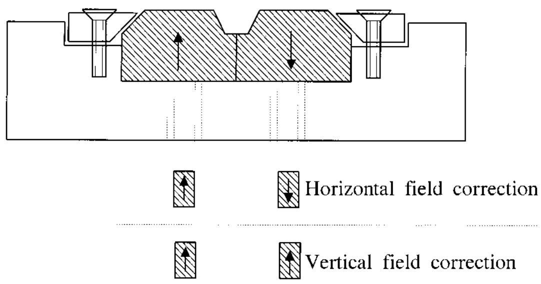

Figure 2
Method of field correction of the in-vacuum vertical undulator. By changing the direction of magnetization of chip magnets, both horizontal and vertical fields can be generated.

magnets into holes in the magnet holder, a method first employed at KEK (Yamamoto, 1990), as shown in Fig. 2. There are two holes in each holder and it is possible to intensify or weaken either the horizontal or the vertical field. The electron orbit calculated using the measured magnetic field after correction is shown in Fig. 3 for various gap values. The straight line between −400 and 400 mm represents the drift space between two undulators. It is found that the variation of the trajectory with changes in the gap is small.

The peak horizontal field measured at the minimum gap of 8 mm was 0.493 T, 2% less than the ideal field. This means that the minimum available energy is 6.7 keV.

Fig. 4 shows a spectrum calculated using the measured magnetic field at the minimum gap. The dots indicate the peak flux density calculated using the ideal field. Up to the seventh harmonic, the intensity is almost equivalent to the ideal intensity.

After the correction, the field integrals were measured by the lock-in amplifier method (Tanabe & Kitamura, 1998). The results showed that the maximum field integral was 100 G cm for the vertical field and 65 G cm for the horizontal field. If no correction is made, the beam axis may change when the gap is changed to tune the photon energy. In order to correct these field integrals, long coils surrounding the vacuum chamber were attached. The current in the coil was determined to minimize the closed-orbit distortion (COD) due changes in the gap (Kitamura, 1998). The maximum current needed for the correction was 15 A turns.

Fig. 5 shows the measured uniformity of the field for various gap values. Also shown are the calculated data in the case of an ordinary magnet array for a horizontal field (no gutter in the center). It is found from the figure that the uniformity of the SPring-8 type undulator is superior to that of an ordinary one.

4. Conclusions

The construction of the vertical undulator for BL45XU at SPring-8 has been completed. Magnetic performance, such as the magnetic field and the spectral intensity, has been found to be as good as expected.

The installation in the storage ring and the bake out for ultra-high vacuum was completed in November 1996. The pressure in the vacuum chamber of the ID reached 1.0×10^{-8} Pa after the bake-out process [see Hara *et al.* (1998) for details of the bake out of the in-vacuum undulator to achieve ultra-high vacuum].

In July 1997, the gap of ID45 was successfully closed to its minimum value (8 mm). The monochromated photon beam was

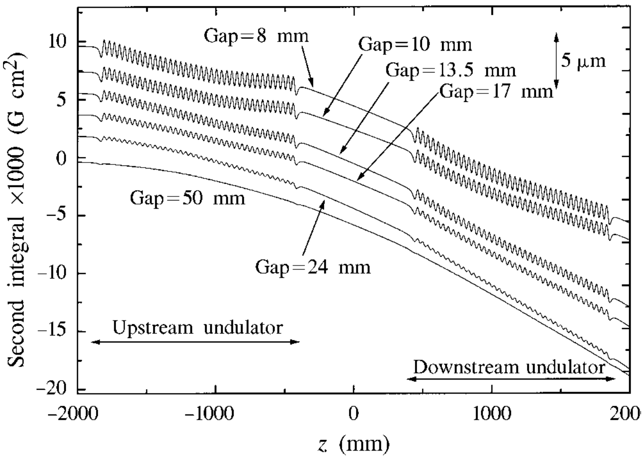

Figure 3
Electron orbits for various values of the gap after correction.

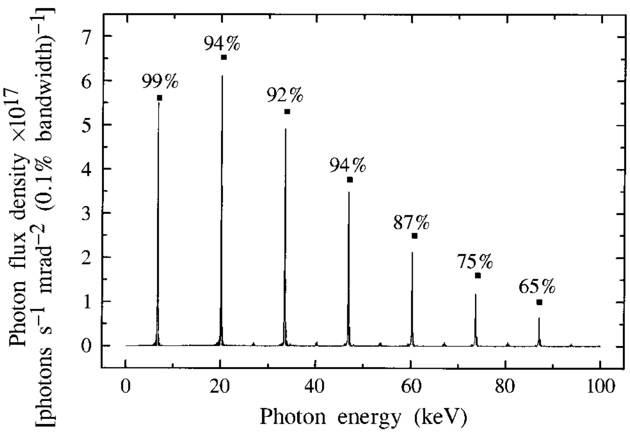

Figure 4
Spectrum calculated using the measured field at a gap of 8 mm. The dots indicate the peak flux density calculated using the ideal field.

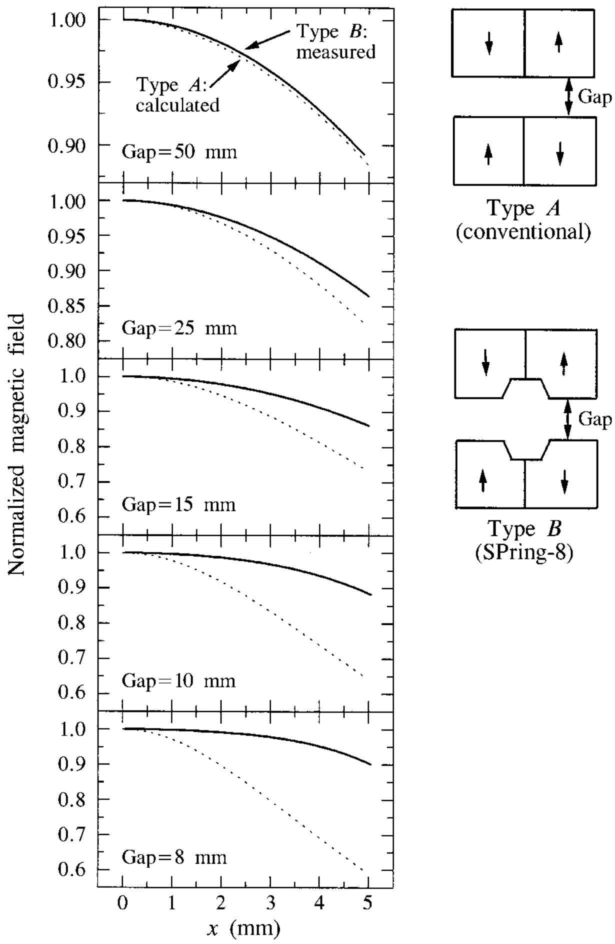

Figure 5
Horizontal uniformity of the field. Also shown is the calculated uniformity in the case of an ordinary magnet arrangement of the horizontal field.

then transported into the experimental station and it was confirmed that the polarization was vertical (Yamamoto, 1998). This means that the constructed ID works well as a vertical undulator.

References

Hara, T., Tanaka, T., Tanabe, T. Maréchal, X.-M., Okada, S. & Kitamura, H. (1998). *J. Synchrotron Rad.* **5**, 403–405.

Kitamura, H. (1998). *J. Synchrotron Rad.* **5**, 184–188.

Tanabe, T. & Kitamura, H. (1998). *J. Synchrotron Rad.* **5**, 475–477.

Yamamoto, M., Fujisawa, T., Nakasako, M., Tanaka, T., Uruga, T., Kimura, H., Yamaoka, H., Inoue, Y., Iwasaki, H., Ishikawa, T., Kitamura, H. & Ueki, T. (1995). *Rev. Sci. Instrum.* **66**, 1833–1835.

Yamamoto, M., Kumasaka, T., Fujisawa, T. & Ueki, T. (1998). *J. Synchrotron Rad.* **5**, 222–225.

Yamamoto, S. (1990). *Photon Factory Act. Rep.* **8**, R11–R13.

Yamamoto, S., Shioya, T., Hara, M., Kitamura, H., Zhang, X. W., Mochizuki, T., Sugiyama, H. & Ando, M. (1992). *Rev. Sci. Instrum.* **63**, 400–403.