In-vacuum Undulators of Exotic Type

The developments of in-vacuum undulators consisting of permanent magnet arrays located in an ultra-high vacuum has lead to generation of various in-vacuum undulators of exotic type to obtain hard X-rays that possess not only special polarization characteristics but also unique higher harmonics properties. One of such devices is an in-vacuum tandem vertical undulator, used to obtain vertically polarized X-rays. Another is an in-vacuum figure-8 undulator for horizontal and vertical polarizations. The third is an in-vacuum helical undulator which generates only the fundamental, without any higher harmonics. Figure 1 shows spectral brilliances obtained from these undulators, while Table 1 lists their main parameters.

The in-vacuum tandem vertical undulator is composed of the two identical segments which produce vertically-polarized X-rays having different photon energies on the same axis [1]. The periodic length is 37 mm, with 37 periods per segment. A maximum field of 0.5 T is obtained with a minimum gap of 8 mm. A representative magnet unit of the vertical undulator is shown in Fig. 2. The unit has a gutter, which enhances production of the magnetic field with wide uniformity in the horizontal direction. Figure 3 shows a comparison of the calculated field uniformity of this undulator with and without the gutter. The attached beamline, used for structural biological studies is optimized for use of vertical polarized X-rays. For example, a diamond monochromator is operated as a beam splitter in the horizontal direction [2].

The structure of the six magnet array comprising the figure-8 undulator is shown schematically in Fig. 4. The outer four magnet arrays generate the horizontal field, while the central two arrays generate the vertical field. The period length of

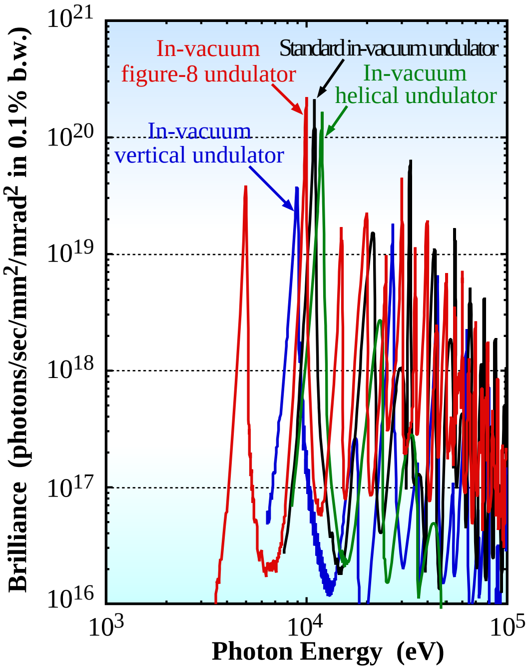

Fig. 1. Spectral brilliances obtained from the in-vacuum undulators of exotic type, an in-vacuum vertical undulator, an in-vacuum figure-8 undulator and an in-vacuum helical undulator. For comparison, a spectrum from a standard in-vacuum undulator is also shown.

Table I : In-vacuum undulator of exotic type. For comparison, the parameters of a standard in-vacuum undulator are also listed.

Name	λ_u (mm)	N	G_{min} (mm)	B_{max} (tesla)	K_{max}	Polarization	Energy (keV)
In-vacuum vertical undulator	37	2×37	8.0	0.5	1.7	vertical	6.6 - 70
In-vacuum figure-8 undulator	26 - 52	172	5.0	1.02	2.6	hor /ver	4.1 -20
In-vacuum helical undulator	36	125	7.0	0.33	1.1	circular	7.6 -16.5
Standard in-vacuum undulator	32	140	8.0	0.87	2.6	horizontal	4.3 - 90

the horizontal field is twice longer than the vertical field, so that a projection of the electron trajectory in the transverse plane looks like a figure-8. Originally, the figure-8 undulator design was developed to obtain a special type of radiation with low central power density, similar to helical undulator, which is the most important characteristic of the figure-8 design [3]. However, this design has another important characteristic: both horizontal and vertical polarization are available [4]. Figure 5 shows a radiation pattern obtained on the fluorescence screen.

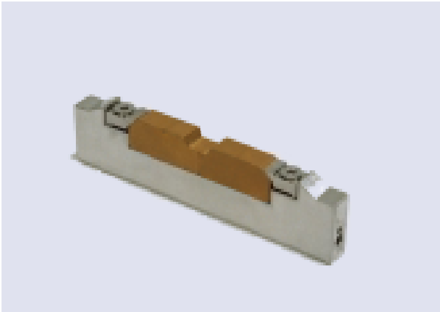

Fig. 2. Magnet unit of the vertical undulator.

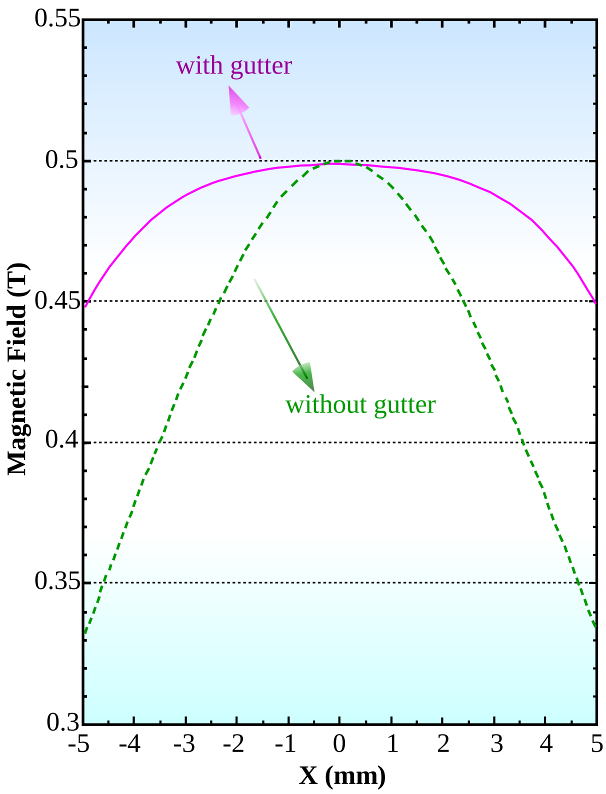

Fig. 3. Comparison of calculated field uniformity using an in-vacuum vertical undulator with and without gutter.

Some scientific inquiries require a radiation source with high photon flux and moderate energy resolution. To meet this requirement, we have developed an in-vacuum helical undulator designed to generate radiation in the X-ray region. The period length is 36 mm, with 125 periods. A maximum field of 0.36 tesla is obtained with a gap of 7 mm. It is well-known that the on-axis radiation from helical undulators does not include higher harmonics. Therefore, we can obtain quasi-monochromatic X-rays by using only a spatial filter. In Fig. 6, the spectral flux is calculated for various aperture values of the spatial filter by making the aperture smaller. Finally, a relative bandwidth of 1.5 % is obtained, which is small enough to perform small-angle scattering experiments using the attached beamline without a monochromator.

The radiation is circularly-polarized, which is not important for the purposes of the present beamline. Therefore, the device has no system for switching helicity. It should be noted that variable-polarization undulators [5, 6] are very important tools for experiments in the soft X-ray region, for which no good phase retarder is available. In the X-ray region, however, variable polarization can be obtained easily by the combination of a planer undulator and a crystal phase retarder [7]. This system has higher reliability; the system has no effect on the stored beam, and both right- and left-hand polarization is obtained on the same axis. In addition, the switching speed of helicity is higher than 40 Hz.

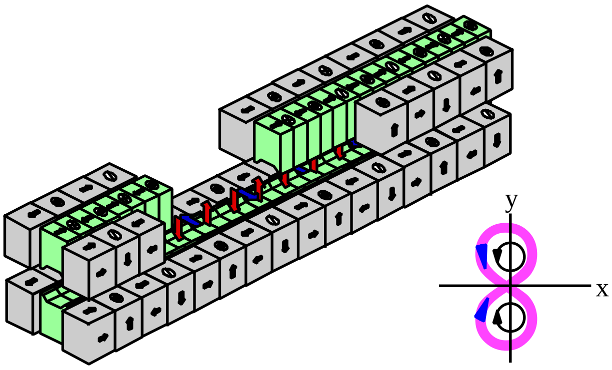

Fig. 4. Magnet design of the in-vacuum figure-8 undulator.

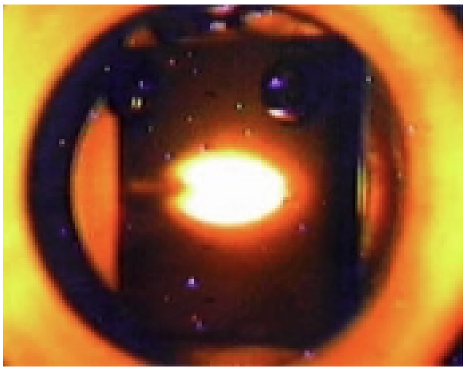

Fig. 5. Image of the radiation obtained from the in-vacuum figure-8 undulator.

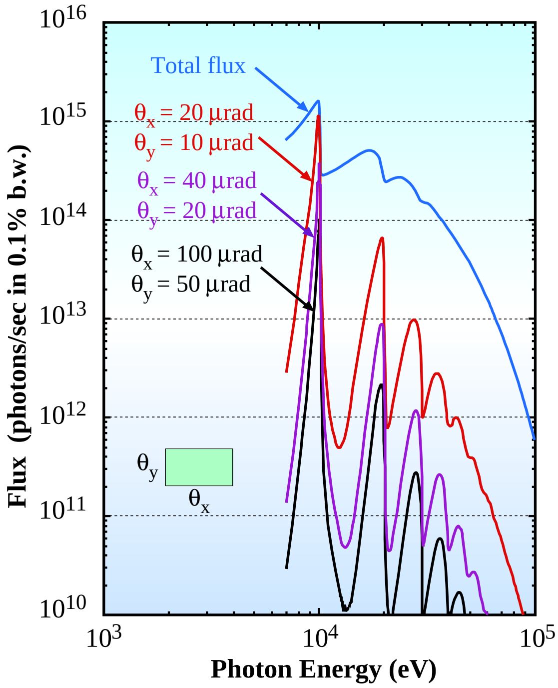

Fig. 6. Spectral flux of the in-vacuum helical undulator calculated for various aperture values of the spatial filter.

References

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