Insertion Devices

J. Synchrotron Rad. (1998). **5**, 401–402

Performance of a fixed-taper in-vacuum undulator at SPring-8

Xavier-Marie Maréchal

JAERI-RIKEN SPring-8 Project Team, Kamigori-cho, Ako-gun, Hyogo 678-12, Japan. E-mail: marechal@spring8.or.jp

(*Received 4 August 1997; accepted 18 November 1997*)

With an in-vacuum undulator, the smallest gaps can be used to achieve high-brilliance radiation within a small spectral width around the harmonics of the fundamental. However, some experiments require a scan over a much wider range of energy within timescales which are impossible to reach *via* gap tuning. For standard undulators a flat spectrum is usually obtained by using a variable tapered gap. Unfortunately, the mechanical design of the in-vacuum undulator used at SPring-8 is hardly compatible with the extra degree of freedom necessary to adjust the taper mechanically. New magnetic designs are investigated to overcome this problem; their performances are compared with the performances of a fixed-taper in-vacuum undulator for a source of photons in the 5–15 keV range (energy of the fundamental) with an energy width of 1.5 keV.

Keywords: taper undulators; in-vacuum undulators.

1. Introduction

With the low gap achieved by in-vacuum undulators at SPring-8, high-brilliance photon beams are generated within a small spectral bandwidth (typically a few 10 eV) centred on harmonics of the fundamental. Energy tunability is then usually obtained by varying the undulator gap. In some experiments, such as time-resolved EXAFS, the photon energy shall be scanned over a range a hundred times larger than the natural bandwidth (a few keV), and within timescales (a few milliseconds per energy point, *i.e.* about a couple of seconds for the whole spectral range) several thousand times smaller than the times required to change the gap.

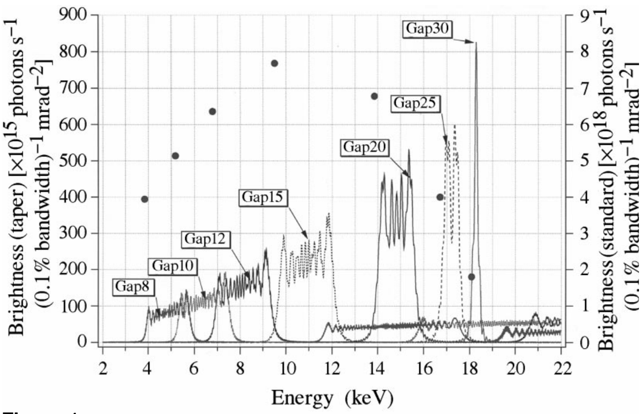

Figure 1
Spectrum of a tapered magnetic gap undulator (taper 3 mm). The gap is changed from 8 to 30 mm. Dots (right-hand scale) give the brightness value for no taper.

A flat spectrum can be obtained with a tapered undulator, except for wigglers and bending magnets (Kroll *et al.*, 1981). In an undulator with a tapered magnetic gap, the entrance and exit gap are different and usually can be adjusted independently: the amplitude of the magnetic field changes along the electron path, the peak intensity decreases and the spectrum broadens, the resulting spectral bandwidth being a function of the change in amplitude of the magnetic field (the amount of taper) (Shih & Caponi, 1982). When the gap is changed, the amount of taper can be adjusted accordingly to preserve the desired spectral bandwidth. Unfortunately, the constraints on the in-vacuum undulators, as developed at SPring-8, are hardly compatible with the extra degree of freedom necessary to adjust the mechanical taper. If an in-vacuum undulator is to be built at SPring-8, the mechanical taper has to be fixed.

We present in the following a study for the realization at SPring-8 of a source of photons in the 5–15 keV range (energy of the fundamental) with a spectral width of 1.5 keV, following the requirements and preliminary study of Hasnain (S. S. Hasnain, private communication). Another possible source, a 'period-tapered' undulator, is also presented. Other solutions (helical-taper undulator, tandem-taper undulator) have been investigated (Maréchal, 1997) but are not presented here.

All computations of magnetic fields with *RADIA* (Chavanne & Elleaume, 1990), and brightness and flux with *B2E* (Maréchal & Elleaume, 1991), assume an error-free pure permanent-magnet undulator and neglect the effect of permeabilities. Optical characteristics of the electron beam (energy E = 8 GeV, current 100 mA) are those of the SPring-8 high-β sections, *i.e.* the horizontal (vertical) betatron function β_x = 24 m (β_y = 11.9 m), and the horizontal emittance ε_x = 5.55 nm rad, with 10% coupling.

2. Spectral performances of a fixed-taper undulator at SPring-8

The undulator used here has 139 periods of 32 mm. The gap is defined where it is minimum, and the taper, expressed in millimetres, corresponds to the gap difference between the entrance and exit of the undulator.

Fig. 1 shows the typical spectrum of a fixed-taper undulator (3 mm taper) for different gaps ranging from 8 to 30 mm in the filament electron beam approximation (no divergence or angular spread). The dots give the value of the brightness on the first harmonic for a standard (no taper) undulator. Note that the scale for the standard undulator (right-hand scale) is one order of magnitude higher than the one used for the tapered one (left-hand scale). The value of the peak half-width is plotted on Fig. 2

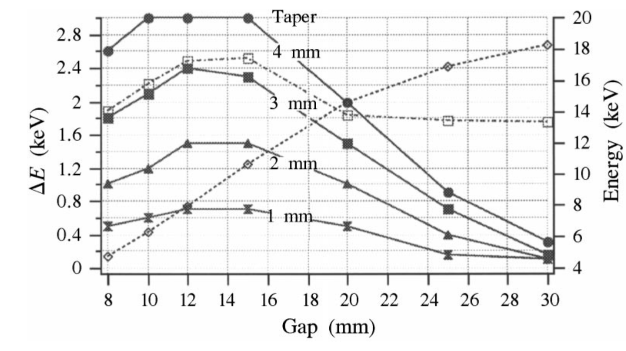

Figure 2
Peak half-width ΔE *versus* gap for different values of the mechanical taper. The dot-dashed line includes the beam emittance (taper 3 mm).

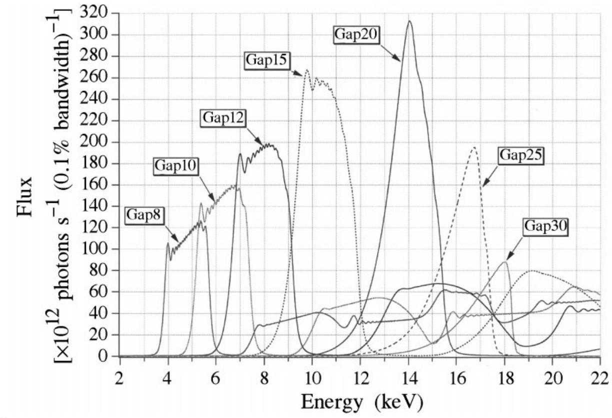

Figure 3
Flux from a tapered magnetic gap undulator (taper 3 mm) observed through a 2 × 2 mm slit. The gap is opened from 8 to 30 mm.

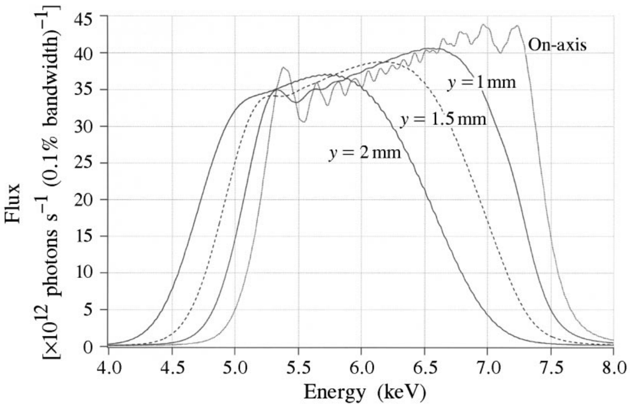

Figure 4
Flux from a tapered magnetic gap undulator (taper 3 mm) observed through a 1 × 1 mm slit. The centre of the slit is shifted vertically off-axis.

for different values of the taper, as a function of the gap: 3 mm represents the minimum amount of taper to obtain at least a 1.5 keV FMWH in the 5–15 keV range. Eventually, when the electron beam size and divergence is taken into account, the peak half-width increases, the effect being stronger at a larger gap.

Another effect of the finite emittance is to smooth out the oscillations in the peak. In Fig. 3 the fluxes are those observed through a 2 × 2 mm square slit, located 50 m away from the source point, while the gap is opened from 8 to 30 mm. Remaining intensity fluctuations, which could be a problem for the detectors, can be suppressed by slightly shifting the slit off-axis in the vertical direction, without any significant loss in photon flux or available energy range (Fig. 4).

3. Period-tapered undulator

However, a drawback of the fixed-taper undulator is the slowly decreasing bandwidth and peak sharpening observed when the gap is increased: at large gaps the relative variation of the magnetic field is small and the peak is similar to the peak emitted by a non-tapered undulator.

In fact, it is also possible to taper the period of the undulator to obtain a flat spectrum. If one wants to change the period of the magnetic field but keep its peak value constant along the undulator axis, the size of the magnets has to be chosen carefully

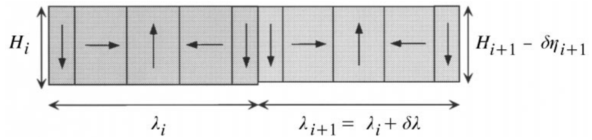

Figure 5
Schematic diagram of the period-tapered undulator: the average period is 32 mm, and each period is different from the previous one by 0.03 mm. The height difference between the first and the last period is 11 mm.

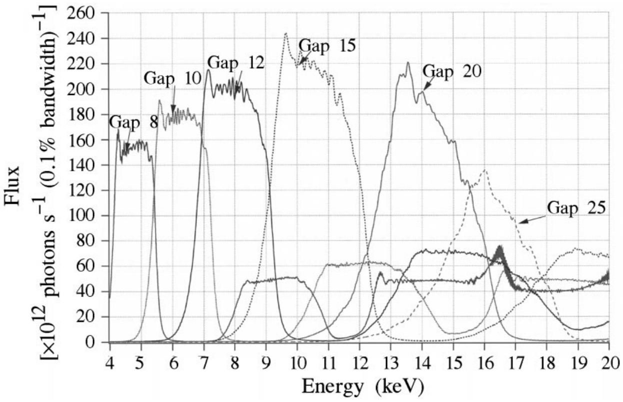

Figure 6
Flux from a period-tapered undulator observed through a 2 × 2 mm slit.

(Maréchal, 1997). Here, each of the 139 periods of the undulator are different: each period consists of five blocks (Fig. 5). The magnet height is changed from period to period in such a way to keep the peak field constant. The resulting spectrum is shown in Fig. 6, for gaps of 8–25 mm. While there is some gain in intensity below 8 keV, at higher energy the peaks are flattened.

4. Conclusions

An undulator with a fixed mechanical taper could provide, on the first harmonic, high flux in the 5–15 keV range with a large bandwidth ($\geq$1.5 keV) at SPring-8. Higher energies would only be covered using higher harmonics. Between 5 and 15 keV, and depending on the aperture size, one observes fluxes in the 10^{14}–10^{15} photons s^{-1} (0.1% bandwidth)$^{-1}$ range, or three orders of magnitude larger than the fluxes obtained with a bending magnet. However, a drawback of the fixed taper is the decreasing bandwidth, and the peak sharpening at high energies (reached when the gap is increased). This can be slightly improved by using a period-tapered undulator. However, the problem is then the complexity (and thus the cost) of the new magnetic arrangement due to the fact that each period is different.

References

Chavanne, J. & Elleaume, P. (1990). ESRF internal report ESRF-Synchrotron Radiation/ID-90–46. ESRF, Grenoble, France.
Kroll, N. M, Morton, P. L. & Rosenbluth, M. N. (1981). *IEEE J. Quantum Electron.* **17**(8), 1436–1468.
Maréchal, X.-M. (1997). SPring-8 Engineering Note. SPring-8, Kamigori-cho, Ako-gun, Hyogo 678–12, Japan.
Maréchal, X.-M. & Elleaume, P. (1991). ESRF internal report, Synchrotron Radiation/ID-91–47. ESRF, Grenoble, France.
Shih, C.-C. & Caponi, M. Z. (1982). *Phys. Rev. A*, **26**(1), 438–450.