Use of the 30 m Straight Sections in the SPring-8

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1. Introduction

The 30 m straight section is one of the unique characteristics of the SPring-8 storage ring. In this paper some preliminary studies of various utilization of the 30 m straight sections are presented. Here we have mostly omitted the beam dynamics issues which are to be resolved for their use. The first candidate is an ultra-bright X-ray undulator for the 1 km beam line primarily used for the experiments utilizing a plane-wave characteristics. The second is a long ultra-bright XUV helical or "Figure-8" undulator. In both cases, one can choose relatively loose focusing of the electron beam so that the divergence angle of the radiation can be made minimal. This feature is rather difficult to achieve in a mini-pole undulator in which the beam must be tightly focused to clear the small gap. The third is so-called "highly degenerated X-ray light source" which uses the principle of the self-amplified spontaneous emission.

2. 26 m undulators

It must be noted that for extremely long undulators (large N_u, the inhomogeneous broadening becomes non-negligible. Total spontaneous emission width is given by [1]:

$$\left(\frac{\Delta\omega}{\omega}\right)^2_T = \left(\frac{\Delta\omega}{\omega}\right)^2_h + \left(\frac{\Delta\omega}{\omega}\right)^2_E + \left(\frac{\Delta\omega}{\omega}\right)^2_x + \left(\frac{\Delta\omega}{\omega}\right)^2_y \quad (1)$$

where $\left(\frac{\Delta\omega}{\omega}\right)_h \approx \frac{1}{2N_u}$;

$$\left(\frac{\Delta\omega}{\omega}\right)_E \approx 2\left(\frac{\Delta E}{E}\right); \quad \left(\frac{\Delta\omega}{\omega}\right)_x = \frac{2\gamma^2}{1+K^2}\left(\frac{\sigma^4_{x'}}{2} + 2\left(\frac{K\pi}{\gamma\lambda_u}\right)^4 h^2_x \sigma^4_x\right)^{\frac{1}{2}}$$

The same expression is used for y, and $h_x = 0$, $h_y = 2$ for a planar ID or $h_x = 1$, $h_y = 1$ for a helical ID.

As is shown above, the electron energy spread tends to become a limiting factor for the spectrum width in a long undulator.

Figure 1 shows the calculated brilliance (photons/s/mrad^2/mm^2/0.1% B.W.) as a function of the photon energy for a conventional planar undulator (beta-x in the mid point = 8.0 m). Fig. 2 shows the effect of the energy spread on the spectrum. Here the spectral width is several times greater than the homogeneous one due to the inhomogeneous broadening.

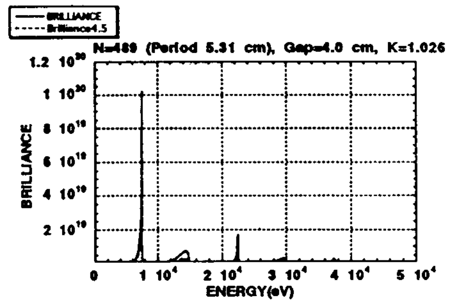

Fig. 1 Brilliance of the radiation from a 26 m conventional planar undulator. The dotted line is the equivalent radiation from 4.5 m undulator.

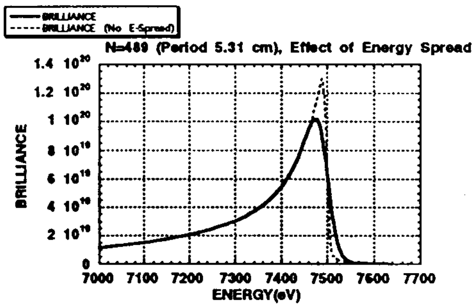

Fig. 2 The spectral broadening due to the electron beam energy spread. The dotted line is the spectrum without energy spread.

For the XUV undulators, it may be necessary to lower the electron beam energy in order to achieve the maximum brilliance. At the normal operational energy, a large K is required to make the radiation wavelength larger, which poses a serious heat problem in the case of a planar undulator. To circumvent the problem the "figure-8" undulator [2] can be used. Table 1 shows the comparison between a conventional planar undulator and a figure-8 undulator in terms of power density on axis.

Table 1. Comparison of the on-axis radiation power density between figure-8 undulators and conventional planar ones.

Power Density on Axis (kW/mrad^2)		
Photon Ev (eV)	200	310
Figure-8	4.529	1.903
Planar	744.3	937.5

3. Highly degenerated light source

Brilliance of radiation can be often described as the number of photons in the six dimensional phase space (the meaning of the symbols is considered to be obvious in the following).

$$B = \frac{d^6 N}{dx\, dx'\, dy\, dy'\, dt \left(\frac{d\omega}{\omega}\right)} \qquad (2)$$

From the uncertainty principles, one can define the minimum uncertainty volume of this 6-D phase space ($\equiv V_{min}$)

$$V_{min} = \lambda^3 / 8\pi^3 c. \qquad (3)$$

Bose degeneracy can be described as:

$$N_B = B_{peak} \times V_{min} \times \frac{1}{2} \qquad (4)$$

the factor of one-half comes from the consideration of a degree of freedom of the polarization. We call the radiation with $N_B >> 1$, highly degenerated light and so far very few light source other than lasers are able to produce such kind of light. There have been numerous proposals on short-wavelength high-gain free electron lasers (FEL's) [3], but no experimental attempt at the wavelength below IR has been made. If successful, the laser power would grow exponentially with the distance; therefore a long straight section in the SPring-8 storage ring would be a natural candidate for that scheme.

According the 1-D theory by Pellegrini, et al [4], the figure of merit for high gain FEL's ,which is sometimes called the Pierce parameter, is described as follows:

$$\rho = \left(\frac{K^2 [JJ] r_e n_b \lambda_u^2}{32 \pi \gamma^3} \right)^{\frac{1}{3}} \qquad (5)$$

where $[JJ]=[J_0(\xi) - J_1(\xi)]^2$

with $\xi=K^2 / 4(1+K^2/2)$,

r_e : Classical Electron radius

$n_b = I_{peak} / ec2\pi\sigma_x\sigma_y$.

This theory can be applied provided the following conditions are fulfilled.

a) Small Relative Energy Spread: $\left(\frac{\Delta E}{E}\right) < \rho$

b) Small Transverse Emittance: $\varepsilon_x < \lambda / 4\pi$

c) Small Radiation Diffraction:

$$\rho > \lambda_u \lambda / 4\sqrt{3}\pi^2 \sigma_i^2 \ \text{(i=x or y)}$$

Table 2 shows a set of parameters calculated based on this theory with setting the beam energy at 3 GeV. It should be noted that the requirement on the electron beam current is very demanding even with rather simplified estimations. Therefore more study and experience on the ring performance are necessary to determine more concrete settings.

Table 2. Parameter list of self-amplified spontaneous emissions. (E = 3.0 GeV)

λ (nm)	4.0		8.0
Gap (cm)	2.0	4.0	2.0
λ_u (cm)	5.04	7.02	5.84
K	2.990	2.42	4.109
L (m)	26	←	←
N_u	515	370	445
ε_x (m·rad)	3.0×10^{-10}	←	5.8×10^{-10}
ε_y (m·rad)	1.5×10^{-10}	←	2.9×10^{-10}
$\langle\beta_x\rangle$ (m)	5.1	←	5.3
$\langle\beta_y\rangle$ (m)	10.2	←	10.6
I_{peak} (A)	1200	**2400**	1500
$\left(\frac{\Delta E}{E}\right)$	4.0×10^{-4}	←	5.0×10^{-4}
P_{sat} (GW)	6.98	19.4	10.1
$\frac{\Delta\omega}{\omega}$	1.94×10^{-3}	2.7×	2.24×10^{-3}

Instead of generating the radiation from the vacuum fluctuation, one might attempt to use a FEL to amplify radiation from a seed laser. Recently there have been observations of the light at 3.94 nm from the calcium ions by the recombination plasma scheme [5] which might become a viable seed light in the future. In that case the requirement for the beam current will be slightly less stringent at the expense of tunability. Whether the oscillator configuration is feasible or not almost entirely depends on the availability of reflective mirrors and grating which could be used to extract a part of radiation from the cavity.

References

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