A Local Compensation Scheme for Insertion Devices in the 8 GeV Electron Storage Ring SPring-8

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Abstract

When insertion devices (IDs) are installed in a low-emittance storage ring of electrons, lattice functions will be modified. The modification will be significant for IDs with strong field like superconducting wigglers. We estimate the effects of IDs installed in the SPring-8 storage ring and propose a correction scheme for deviations of linear lattice parameters. We also discuss the effects of IDs on emittance, energy spread and dynamic aperture.

1 INTRODUCTION

In the third generation synchrotron light sources, it is required to keep the quality of photon beams as high as possible, and this quality depends on the quality of a stored electron beam. The electron beam is affected by insertion devices (IDs) installed in the storage ring. We will then need to perform the following corrections: (i) fast (< a few tens Hz) feedback for photon beam axis (ii) precise tuning of the envelope function in straight sections where IDs are installed (iii) minimization of the effects of wigglers on lattice parameters. The first correction can be performed with steering magnets, and the second with quadrupole magnets. The last point is a main concern of the present work.

In the following we examine the effects of IDs installed in the SPring-8 storage ring[1] and present a possible compensation scheme[2] for deviations of linear lattice parameters. In order to highlight the effects of IDs we will sometimes take superconducting (S/C) wigglers as an extreme example, though at the present time we have no definite plan of installing high-field S/C wigglers in the SPring-8 storage ring. One of our aim is to point out the possibility and limit of installing high-field wigglers. In this context we will also discuss the effects of IDs on emittance, energy spread and dynamic aperture. As a possible application of S/C wigglers we estimate yield of slow positrons created through the electron-positron pair production process.

2 LOCAL COMPENSATION FOR WIGGLER INSERTION

The lattice of the SPring-8 storage ring is of DBA type as shown in Fig. 1. IDs are installed in the magnet free section marked as "ID". Installation of wigglers generates dispersion η in the horizontal (H) direction and causes deviations of tune ν and envelope function β in the vertical (V) direction (see e.g. [3]). As an example we install one S/C wiggler which consists of an 8T central pole of 10cm long and two auxiliary 2T poles of 20cm long put in both sides of the central pole. The deviations of ν_V and β_V in this case are listed in Table 1.

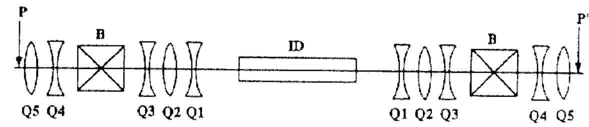

Figure 1: SPring-8 lattice (DBA)

Table 1: Deviations of linear lattice functions

	ν_V	$\Delta\beta_V/\beta_V$ for the cell with ID installed	$\Delta\beta_V/\beta_V$ for the rest of the ring
Wiggler off	16.160	0	0
Wiggler on	16.167	5.2%	5.5%
Wiggler on with local compensation	16.160	2.0%	0.0%

These deviations can be compensated locally by changing the strength (K) of the quadrupole magnets in the cell where IDs are installed. The symmetry points P and P' in Fig. 1 can be used as fitting points; the fitting condition is that ν_H, ν_V, β_H, β_V and η_H should be unchanged at these points. The results for the 8T S/C wiggler are shown in Table 2. After compensation we can recover initial values of lattice functions as shown in the last row of Table 1. Note that the condition of "achromat" has been broken since we changed the strength of Q4 and Q5. However, the dispersion generated by this is small (< 1mm) and its effect on emittance can be neglected. Compensation for wigglers with normal strength can also be performed in the same way as described here.

3 EFFECTS OF INSERTION DEVICES ON EMITTANCE, ENERGY SPREAD, ETC.

A typical value of the natural emittance (ε) of the SPring-8 storage ring is 7.0nm·rad, and our goal of the coupling ratio is 1%. In order to achieve this, residual dispersions (coming from misalignment, field errors, etc.) must be small in both horizontal and vertical directions.

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Table 2: Local compensation for 8T S/C wiggler

Q magnet	$\Delta K/K$
Q1	-2.79%
Q2	-0.52%
Q3	-1.22%
Q4	+1.00%
Q5	+0.27%

We first consider the case of IDs with normal strength. The existence of residual dispersions does not cause any increase in horizontal emittance ε_H, and the effect of IDs on ε_H is to decrease its magnitude (as one expects). On the other hand, the emittance in the vertical direction ε_V is sensitive to the residual dispersion η_V. In Fig. 2 ε_V is plotted for various values of η_V as a function of field strength of the wiggler. In this calculation 20 wigglers were installed at β_V=8m, and the length of the wiggler was assumed to be 4m. Figure 3 is for undulators installed at β_V=10m. The number of undulators is again 20 and the length is 4m. From these figures we conclude that the residual dispersion in the vertical direction should be smaller than a few cm in order to keep the 1% coupling ratio.

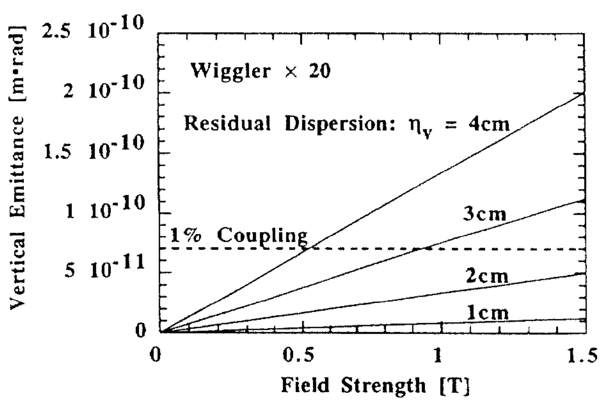

Figure 2: Effects of wigglers on ε_V

We next turn to S/C wigglers. We assume that the S/C wiggler has the same three-pole structure as described in the preceding section except that field strength can be varied. For a 5-10T S/C wiggler the horizontal emittance can stay within a 10% increase if the residual dispersion η_H is within a few cm. The vertical emittance is on the other hand sensitive to the residual dispersion as in the normal ID case discussed above. The situation here is, however, more serious because the strength of the wiggler is so strong that allowable residual dispersions become very small. Figure 4 shows the vertical emittance as a function of the field strength of the S/C

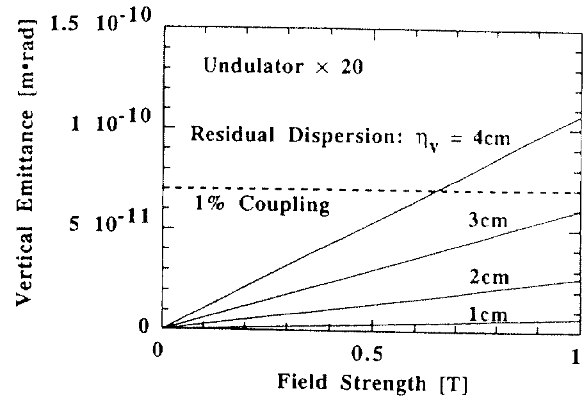

Figure 3: Effects of undulators on ε_V

wiggler. Note that this result is for one S/C wiggler. We hence conclude that in order to install a S/C wiggler with an 8-10T field strength we need to perform fine tuning of the vertical dispersion; otherwise we have to give up the 1% coupling ratio (and accept ~10% ratio). Further analysis is required to solve this problem, and it is beyond the scope of the present work.

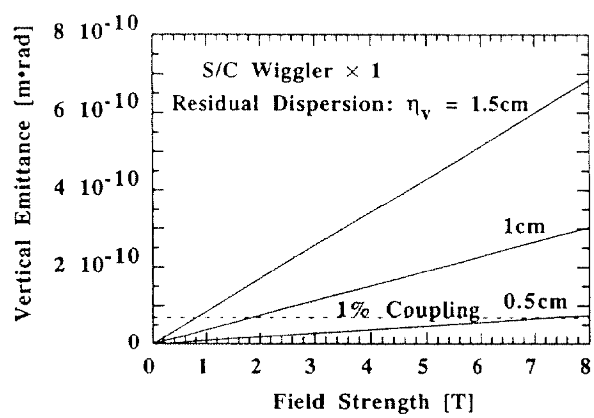

Figure 4: Effects of a S/C wiggler on ε_V

The energy spread $\sigma(\Delta p/p)$ also increases when wigglers are installed. For example, the design value of 1.09×10^{-3} increases to 1.38×10^{-3} when an 8T S/C wiggler is installed.

We have also checked the effects of S/C wigglers on the dynamic aperture of the ring by taking account of sextupole and octupole field components as thin lenses. The resulting aperture was almost the same as that for the initial ring (without IDs). This is because the dynamic aperture is mainly determined by strong sextupole magnets for chromaticity correction (see also [4]).

We should also mention here the problem of heat load associated with S/C wigglers. The 8T S/C wiggler, for example, generates the power of ~60kW for 100mA of the beam current, and the divergence angle of the photon beam is about 15mrad. Such a high power photon beam can not be absorbed easily. A key to solve this problem would be to use the lattice with a 30m-long magnet-free section [5].

4 SLOW POSITRON PRODUCTION WITH SUPERCONDUCTING WIGGLERS

In this section we estimate yield of slow positrons expected to be produced by using 5-10T S/C wigglers (see also [6]). The slow positron production is one of possible applications of S/C wigglers, and the estimation below is just to demonstrate possibilities that SPring-8 will possess in the future.

It is well known[7] that the photon flux of synchrotron radiation from a dipole magnet with bending radius ρ is given by

$$F\,[\text{photons/s/1\%bw/mrad}] = 1.256\times10^{11}\times I\,[\text{A}]\,\gamma\,\frac{\omega}{\omega_c}\int_{\omega/\omega_c}^{\infty} K_{5/3}(x)\,dx \qquad (1)$$

for a 1% bandwidth and for 1mrad of the orbit arc. In this expression I is the beam current, γ is the Lorentz factor of the electron, and $\omega_c \equiv (3/2)\gamma^3 c/\rho$ is the critical photon frequency with c being the speed of light. Photons incident on target slab, e.g. on tungsten slab, will create positrons through electron-positron pair production. The number of positrons produced by a photon with energy $\hbar\omega$ can be calculated by using the simulation code EGS4[8]. If we denote the number of created positrons by $n(\omega)$, the number of expected slow positrons is given by

$$N\,[\text{slow-positrons/s/mrad}] = \kappa\int n(\omega)\,\frac{F(\omega)}{\omega/100}\,d\omega, \qquad (2)$$

where κ is a conversion rate from positrons created in the slab to slow positrons. The value of κ will depend on thickness of the target slab. For example, if we use 10 slabs of 0.5mm thick, keeping them apart from each other, the value of κ in this case will be different from that for a single slab of 5mm thick. In the present estimation, however, we assume that κ~10^{-3}-10^{-4}, independent of the slab thickness.

We evaluated the integral in Eq. (2) for tungsten slab. The results are shown in Table 3. It is worth mentioning the behavior of the integrand: it starts rising at the threshold value of ω, peaks at around 1.5MeV and then falls toward zero with a tail of about 2MeV long.

We can also estimate the slow positron yield by using the following conversion efficiency given in [6]:

$$K_{\gamma\to\text{slow } e^+} \sim 3\times10^{-6}\ (\text{slow } e^+)/(1.5\text{MeV } \gamma)\,.$$

The number of photons available for positron production is obtained by integrating Eq. (1). For 8-10T S/C wigglers the photon number is ~10^{15} [photons/s/mrad/100mA]. Then the yield will be ~10^9 [slow-positrons/s/mrad/100mA], which value is comparable with or even larger than that for most efficient positron sources currently available.

Table 3: N [slow-positrons/s/mrad/100mA] for tungsten slab

Slab Thickness	Field Strength of the Wiggler		
	5T	8T	10T
0.5mm	$6\times10^{10}\times\kappa$	$8\times10^{11}\times\kappa$	$2\times10^{12}\times\kappa$
5mm	$5\times10^{11}\times\kappa$	$7\times10^{12}\times\kappa$	$2\times10^{13}\times\kappa$
10mm	$8\times10^{11}\times\kappa$	$1\times10^{13}\times\kappa$	$3\times10^{13}\times\kappa$
50mm	$1\times10^{12}\times\kappa$	$2\times10^{13}\times\kappa$	$5\times10^{13}\times\kappa$
100mm	$1\times10^{12}\times\kappa$	$2\times10^{13}\times\kappa$	$5\times10^{13}\times\kappa$

5 ACKNOWLEDGMENT

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