EFFECTS OF INSERTION DEVICES ON PLS STORAGE RING

M. G. Kim, K. W. Kim, T. Y. Lee, J. Choi, and I. S. Ko
Pohang Accelerator Laboratory, POSTECH, Pohang 790-784, Korea

Abstract

In the Pohang Light source (PLS), currently only one insertion device (U7) is installed with a plan soon to be used. But two more insertion devices are under fabrication or design, and more will be planned. Effects of the three typical insertion devices for PLS are estimated and simulated. Both linear and nonlinear effects are discussed.

1 INTRODUCTION

The Pohang Light Source has recently installed a U7 undulator, in one of the 12 straight sections of its storage ring, which will be used in the near future. Also, an elliptically polarized undulator (EPU6) is under fabrication [1] and an U10 undulator is under design. (Parameters of the insertion devices are listed in Table 1.) It is, therefore, necessary to evaluate the effects of these insertion devices on the beam dynamics of the storage ring for safe operations. Even though more insertion devices will be installed in the future, these three insertion devices represent typical ones for PLS.

The effects of insertion devices on the beam dynamics are both linear and nonlinear. The linear effects are obviously the linear optics changes, such as tune shifts and breaking of the α=0 condition at the symmetric points. The linear optics changes are readily evaluated and parametrized. Furthermore, the linear optics changes can be reduced, to some extent, by optimizing quadrupoles. On the other hand, the nonlinear effects are very difficult to quantify. The major nonlinear effect of insertion devices is the reduction of dynamic aperture of the electron beam, which can be evaluated by particle tracking techniques with computer codes.

Table 1. Parameters of insertion devices for PLS.

	U7	EPU6	U10
K	6.3	variable	12.1
period(cm)	7	6	10
number of periods	59	25	30
peak field (T)	0.96	Bx=0.47 By=0.69	1.3

Another important effect of insertion devices on electron beams is conducted by their synchrotron radiation. The additional synchrotron radiation due to insertion devices make changes to the equilibrium beam parameters, such as natural beam emittance and energy spread [1]. Below, the effects of the above three insertion devices will be evaluated and discussed.

2 LINEAR EFFECTS

The linear optics change due to insertion devices can be easily obtained by computer codes. The linear tune changes can be calculated even analytically. The averaged Hamiltonian for the undulator motion is given by [2]

$$H = \frac{1}{2}(p_x^2 + p_y^2) + \frac{1}{4k^2\rho^2}(k_x^2 x^2 + k_y^2 y^2) + \cdots .$$

Hence the linear effects are governed by

$$x'' = -\frac{1}{2\rho^2}\frac{k_x^2}{k^2}x, \quad y'' = -\frac{1}{2\rho^2}\frac{k_y^2}{k^2}y,$$

where k_x and k_y are defined by

$$k_x^2 + k_y^2 = k^2 = (2\pi/\lambda)^2,$$

with the insertion device period λ. The PLS undulators (U7 and U10) are all planar undulators, which means that $k_x = 0$ or equivalently $k_y = k$. In this case, the linear optics in the x direction is unchanged, while the linear optics change in the y direction is entirely given by ρ. The vertical tune change due to a planar undulator with length L is given by

$$\Delta\nu_y = \frac{1}{4\pi}\int_{-L/2}^{L/2}\frac{\beta_y}{2\rho^2}ds.$$

But β_y value in a straight section is related to its value at the center by

$$\beta_y(s) = \beta_y(0) + \frac{s^2}{\beta_y(0)},$$

where $s = 0$ denotes the center point. This is an approximation neglecting the edge focusing. Using this equation, we find

$$\Delta\nu_y = \frac{\beta_y(0)L}{8\pi\rho^2}\left[1 + \frac{1}{12}\left(\frac{L}{\beta_y(0)}\right)^2\right].$$

The vertical tune changes due to U7 and U10 are 0.016 and 0.009, respectively, which are small numbers. The combined value 0.025 is not significant yet; it seems unnecessary to try to recover the original tune by readjusting quadrupoles.

On the other hand, the EPU6 have both k_x and k_y. While the planar undulators have fixed parameters for a given gap between magnets, EPU6 have variable parameters, even for a fixed gap, depending upon values of B_x and B_y which vary in combination from 0.0 to 0.47 T and from 0.69 T to 0.0, respectively. The cases of $B_x = 0$, and $B_y = 0$ correspond to the vertical and horizontal linear polarizations of photon beam respectively, and other cases of no zero magnetic field correspond to the elliptical polarization of photon beam. In cases of elliptical polarization, tune changes occur both horizontally and vertically, their amounts varying according to the combination of B_x and B_y values. The maximum vertical tune change is 0.0026 when the horizontal tune change is 0. Also the maximum horizontal tune change is 0.003 when the vertical tune change is 0. Since the values of B_x and B_y are relatively small, the linear effect of EPU6 is negligibly small. These insertion devices certainly break the α=0 condition at the center of the straight section and thus the superperiodicity. But since these are undulators of weak magnetic field, the breaking is very soft. Hence the breaking effect is just the order of other existing errors and it is unnecessary to try to recover the condition.

3 NONLINEAR EFFECTS

The dynamic aperture reduction due to insertion devices could be a serious problem, if it becomes less than the physical aperture. Fortunately, the three PLS insertion devices considered here are all undulators with relatively small peak magnetic fields. To estimate the dynamic aperture with undulators, particle tracking was performed with the computer code RACETRACK [3]. Unlike the linear effects, the nonlinear effects of insertion devices are not controllable at all. Fig. 1 shows the dynamic aperture with U7. The dynamic aperture is certainly reduced, but still big enough for safe operation.

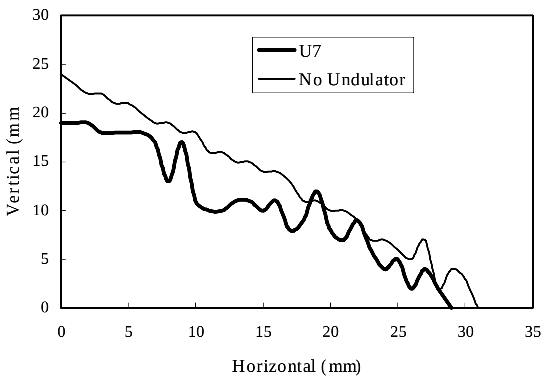

Figure 1: The dynamic aperture with U7

Fig. 2 shows the dynamic aperture with U7 and EPU6. B_x and B_y are chosen to be 0.33 T and 0.50 T respectively.

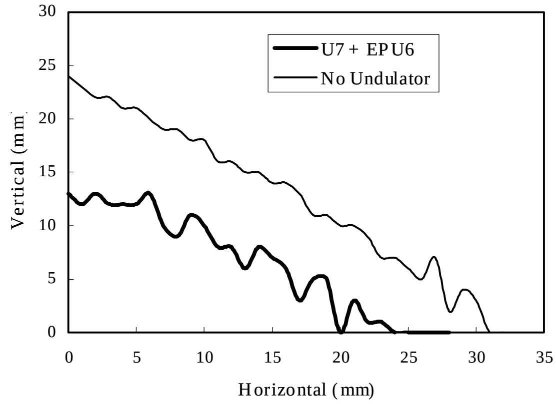

Figure 2: Dynamic aperture with U7 & EPU6

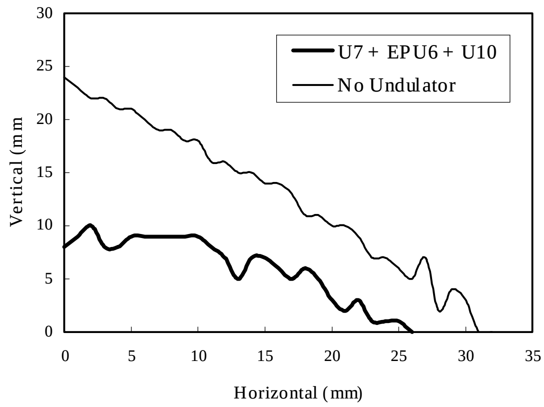

Figure 3: The Dynamic aperture with U7 & EPU6 & U10

Since these magnetic fields of EPU6 are relatively small, the effect on the dynamic aperture is not big either. Finally, Fig. 3 shows the dynamic aperture with U7, EPU6, and U10. Even though the dynamic aperture is reduced further, it is still bigger than the physical aperture of insertion device chambers (especially vertically). Therefore, it is concluded that the dynamic aperture reduction due to the three insertion devices will not be serious at all.

4 EFFECTS ON BEAM PARAMETERS

The natural beam emittance is given by [1]

$$\varepsilon = \frac{55}{32\sqrt{3}} \frac{h}{2\pi mc} \gamma^2 \frac{I_5}{I_2 - I_4}$$

where the I's are synchrotron radiation integrals defined by

$$I_1 = \oint \frac{\eta}{\rho} ds, I_2 = \oint \frac{\eta}{\rho^2} ds, I_3 = \oint \frac{1}{\rho^2} ds,$$

$$I_4 = \oint \frac{\eta}{\rho^3} ds, I_5 = \oint \frac{H}{|\rho|^3},$$

where

$$H = \frac{1}{\beta}\left[\eta^2 + (\beta\eta' - \frac{1}{2}\beta'\eta)^2\right].$$

These integrals except I_3 depend on dispersion values. In general, insertion devices are placed in regions of vanishing dispersion. However, insertion devices generate their own local dispersion, thus affecting beam parameters such as the natural beam emittance and energy spread. To include the insertion device effect, we add their contributions, I_i^w to the original radiation integral I_i^0 to obtain

$$I_i = I_i^0 + I_i^w, i = 1, \cdots 5.$$

In terms of these integrals, the ratio of the new emittance to the old emittance is given by

$$\frac{\varepsilon_x}{\varepsilon_x^0} = \frac{1 + (I_5^w / I_5^0)}{1 + (I_2^w - I_4^w)/(I_2^0 - I_4^0)}.$$

With the thin lens approximation, it is straightforward to evaluate I_i^w. Assuming $\beta' = 0$ inside an insertion device, we obtain [2]

$$I_1^w = \frac{Nl^3}{32\rho_w^3}, I_2^w = \frac{Nl}{\rho_w^2}, I_3^w = \frac{Nl}{\rho_w^3},$$

$$I_4^w = \frac{Nl^3}{32\rho_w^4}, I_5^w = \frac{Nl^3\beta_w}{48\rho_w^5},$$

where ρ_w is the radius of curvature of the insertion devices and β_w is the average value of β over the insertion devices. Since $l/\rho_w << 1$, I_4^w is negligible compared with I_2^w. And the same is true for I_i^0. Hence we find

$$\frac{\varepsilon_x}{\varepsilon_x^0} \cong \frac{1 + (I_5^w / I_5^0)}{1 + (I_2^w / I_2^0)}.$$

Values of I_i^0 are given by

$$I_1^0 = 0.508, I_2^0 = 0.997, I_3^0 = 0.158,$$

$$I_4^0 = -0.223, I_5^0 = 0.002.$$

On the other hand, I_5^w is so small for the three insertion devices that we obtain $I_5^w / I_5^0 \le 10^{-4}$. Hence we have effectively

$$\frac{\varepsilon_x}{\varepsilon_x^0} \cong \frac{1}{1 + (I_2^w / I_2^0)}$$

for the three insertion devices of PLS. Therefore the emittance will be reduced by the insertion devices;

$\varepsilon_x / \varepsilon_x^0 =$ 0.92 for U7,
0.90 for U7 + EPU6,
0.82 for U7 + EPU6 + U10.

Similarly, for the rms energy spread defined by

$$\sigma_\varepsilon^2 = \left(\frac{\sigma_E}{E_0}\right)^2 = \frac{55}{32\sqrt{3}} \frac{h}{2\pi mc} \gamma^2 \frac{I_3}{2I_2 + I_4},$$

we find

$$\frac{\sigma_\varepsilon^2}{\sigma_{\varepsilon 0}^2} = \frac{1 + (I_3^w / I_3^0)}{1 + (2I_2^w + I_4^w)/(2I_2^0 + I_4^0)} \cong \frac{1 + (I_3^w / I_3^0)}{1 + (I_2^w / I_2^0)}.$$

It is straightforward to show that

$\sigma_\varepsilon^2 / \sigma_{\varepsilon 0}^2 \cong$ 0.996 for U7,
0.992 for U7 + EPU6,
0.982 for U7 + EPU6 + U10.

Therefore, these three undulators improve two important beam properties, the equilibrium beam emittance and the energy spread. Especially, the beam emittance will be reduced from 12.1 nmrad to 9.9 nmrad after the installation of the three insertion devices.

5 ACKNOWLEDGMENTS

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6 REFERENCES

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