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EFFECTS OF INSERTION DEVICES ON BEAM EMITTANCES AT THE PHOTON FACTORY STORAGE RING

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Abstract The effects of the insertion devices on the beam emittances are estimated. The results are consistent with the observations.

INTRODUCTION

The Photon Factory storage ring is a 2.5 GeV electron/positron storage ring dedicated to the synchrotron radiation experiments. In this ring, six insertion devices (wigglers) are installed to provide highly brilliant synchrotron lights[1]. Three of them have relatively strong magnetic fields (greater than 1.5 T) and affect the beam emittances through the mechanisms of radiation damping and radiation excitation. In this paper, we estimate the effects of the wigglers on the beam emittances. We also present some preliminary data.

INSERTION DEVICES

The parameters of the wigglers are summarized in Table 1. MPW#13[2] and MPW#16[3] are horizontal multipole wigglers. VW#14[4] is a superconducting vertical wiggler with three poles.

EFFECTS ON BEAM EMITTANCES

The changes in the beam emittances caused by wigglers can be written as follows;

$$(\varepsilon_W/\varepsilon_O) = (I_{5W}/I_{5O}) \,/\, (I_{2W}/I_{2O}) \;,$$

$$(\sigma_{EW}/\sigma_{EO})^2 = (I_{3W}/I_{3O}) \,/\, (I_{2W}/I_{2O}) \;,$$

$$I_{2W} = I_{2O} + \int_W ds(1/\rho_W^{\,2}) \;,$$

$$I_{3w} = I_{3o} + \int_w ds(1/\rho_w^3) ,$$
$$I_{5w} = I_{5o} + \int_w ds(H/\rho_w^3) ,$$
$$H = \gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2 .$$

Here, I_n's are so-called synchrotron integrals and the subscripts "w" and "o" denote the integrals with and without the wigglers, respectively. The ρ_w is the bending radius of the wigglers. Assuming some analytic formulae for ρ_w, we can obtain analytic expressions for I_{nw}'s[5]. In the calculation of the H, the contributions of both the dispersion (η) proper to the ring itself and that produced by the wigglers are included. By using the above formulae, the changes in the beam emittances are estimated and shown in Figures 1, 2, 3. The calculations were done for the present operating energy (2.5 GeV) and also for the lower energy (1.5 GeV), where the effects of the wigglers are expected to be larger.

MPW#16

MPW#16 is installed at a dispersion-free section. The contribution of the horizontal dispersion (η_x) produced by MPW#16 to the radiation excitation in the horizontal betatron motion is negligibly small. Thus, the horizontal emittance (ε_x) is reduced simply by the radiation damping. On the other hand, the energy spread (σ_E) increases as the radiation excitation in the longitudinal motion dominates the radiation damping.

TABLE 1 Parameters of the insertion devices

NAME	Bx(T)	By(T)	λ_u(cm)	N	η_{xo}(m)	P_w/P_o
MPW#13	---	1.5	18.0	13	1.1	0.052
MPW#16	---	1.5	12.0	26	0.0	0.070
VW#14	5.0	---	---	---	0.0	0.071

NOTE Bx and By are the maximum field strengths in the horizontal and vertical directions, res pectively. The λ_u is the period length and N is the number of periods. The η_{xo} is the dispersion function at the wiggler. P_w/P_o is the ratio of the radiation loss caused by each wiggler at its maximum field strength to that caused by the bending magnets.

MPW#13

MPW#13 is installed at a straight section where $\eta_{xo} \sim 1$ m. At 2.5 GeV, the effects of the radiation excitation and the radiation damping almost cancel each other. At 1.5 GeV, the radiation excitation dominates the radiation damping, and then the ε_x increases.

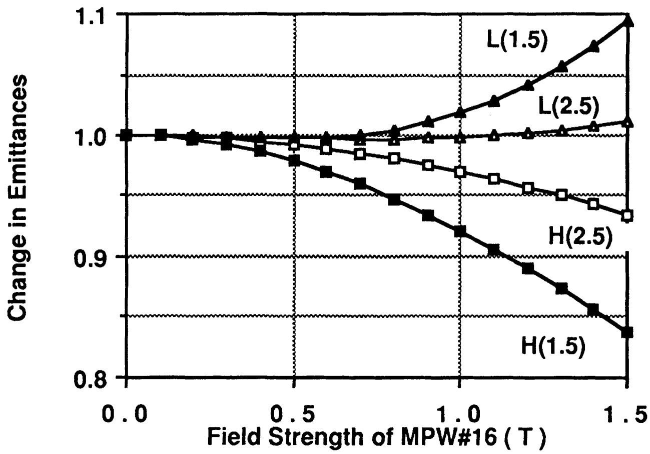

FIGURE 1 Changes in the emittance and the energy spread produced by MPW#16 are shown as the functions of the field strength. "L" denotes (σ_{Ew}/σ_{Eo}) and "H" denotes ($\varepsilon_{xw}/\varepsilon_{xo}$). The numbers in brackets denote the beam energy (2.5 GeV or 1.5 GeV).

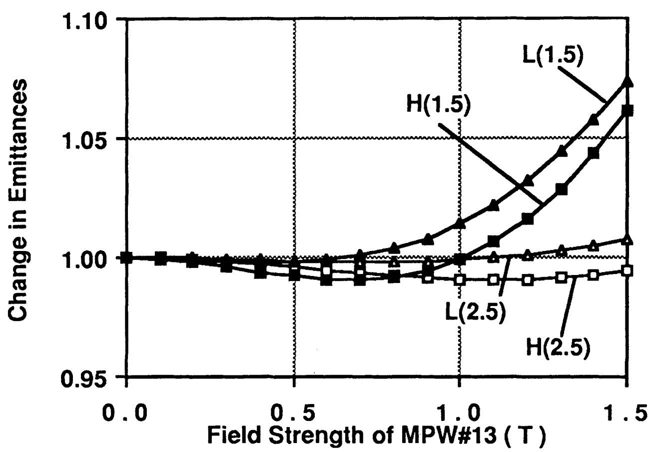

FIGURE 2 Changes in the emittance and the energy spread for MPW#13.

VW#14

VW#14 is installed at a dispersion-free section and the ε_x is reduced by the radiation damping. On the other hand, the vertical emittance (ε_y) is increased. Here, we have assumed $\varepsilon_{yo}=0.02\varepsilon_{xo}$. The vertical dispersion (η_y) produced by VW#14 causes the radiation excitation and increases ε_y.

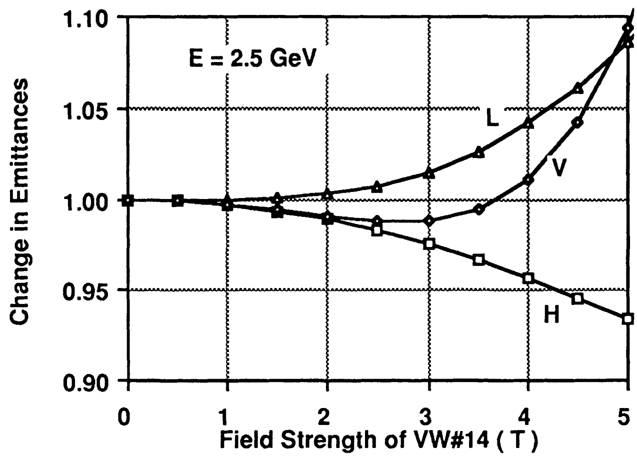

FIGURE 3a Changes in the emittances and the energy spread for VW#14 at 2.5 GeV. "L", "H" and "V" denote (σ_{Ew}/σ_{Eo}), ($\varepsilon_{xw}/\varepsilon_{xo}$) and ($\varepsilon_{yw}/\varepsilon_{yo}$), respectively.

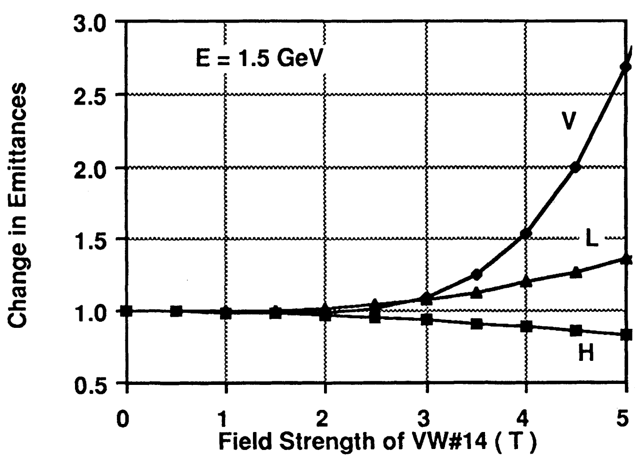

FIGURE 3b Changes in the emittances and the energy spread for VW#14 at 1.5 GeV.

MEASUREMENTS ON BEAM EMITTANCES

In this section, we will present some preliminary data on the changes in the beam emittances caused by the wigglers.[6] We measured the beam sizes at a beam line called BL21 for several field strengths of VW#14 and MPW#16. Because $\eta_x \neq 0$ at the source point of BL21, the horizontal beam size (σ_x) is affected by both changes in ε_x and σ_E. Furthermore, when the wigglers are excited, the linear optics of the ring is also distorted[7]. Therefore, we need the values of σ_E, β and η at the source point of BL21 to determine the emittances. Here, we use the calculated value for σ_E, while for β and η we use the values extrapolated from their measurements near the source point of BL21. The measured data were converted to the transverse emittances using the relations;

$$\varepsilon_x = \{\sigma_x^2 - \eta_x^2(\sigma_E/E)^2\}/\beta_x ,$$

$$\varepsilon_y = \sigma_y^2/\beta_y ,$$

where;

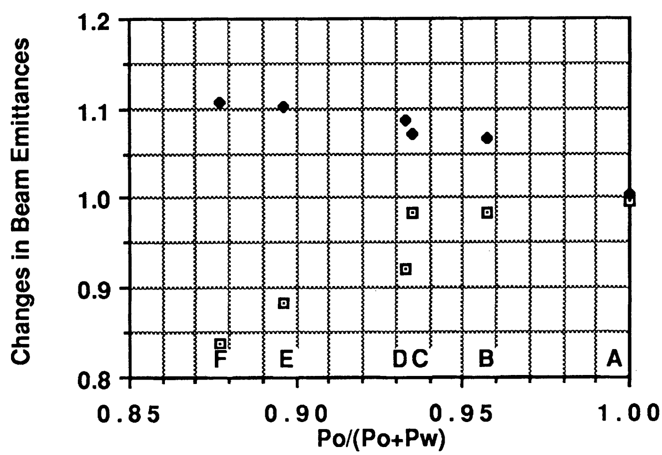

FIGURE 4 Measured data on the transverse emittances are shown as the functions of $P_o/(P_o+P_w)$. White squares are $(\varepsilon_{xw}/\varepsilon_{xo})$. Black squares are $(\varepsilon_{yw}/\varepsilon_{yo})$. The alphabets on the horizontal axis indicates the following cases;
A: VW#14 0 T and MPW#16 0 T, B: VW#14 0 T and MPW#16 1.2 T
C: VW#14 0 T and MPW#16 1.5 T, D: VW#14 5 T and MPW#16 0 T
E: VW#14 5 T and MPW#16 1.2 T, F: VW#14 5 T and MPW#16 1.5 T.

$$\sigma_{x,y} = \sigma_{x,y}^{dsgn}(\sigma_{x,yw}/\sigma_{x,yo})^{meas} ,$$
$$\beta_{x,y} = \beta_{x,y}^{dsgn}(\beta_{x,yw}/\beta_{x,yo})^{meas} ,$$
$$\eta_{x} = \eta_{x}^{dsgn}(\eta_{xw}/\eta_{xo})^{meas} .$$

Here the superscript "dsgn" denotes the design value without wigglers and "meas" denotes the measured value. In Figure 4, the relative changes of the transverse emittances ($\varepsilon_{x,yw}/\varepsilon_{x,yo}$) are plotted as the functions of $P_o/(P_o+P_w)$, where P_o is the radiation loss caused by the bending magnets and P_w is that caused by the wigglers. In the case of MPW#16 and VW#14, it can be considered that ε_x is reduced simply by the radiation damping because of zero dispersion at their locations, and so the changes in ε_x may be approximated by ($\varepsilon_{xw}/\varepsilon_{xo}$) = $P_o/(P_o+P_w)$. The data on ε_x are consistent with this expression. On the other hand, ε_y seems to increase with the excitation of the wigglers. One of the reasons is the contribution of the vertical wiggler, VW#14, on ε_y (see Figure 3a). The other is that the increase of σ_E may contribute to the increase of σ_y, since the measurement indicates that η_y is not strictly zero at the source point of BL21.

SUMMARY

The changes in beam emittances produced by the wigglers are estimated. The measured data on the beam emittances are consistent with the calculations. It is also demonstrated that the effects of wigglers will be more significant for low energy rings, when the wigglers have high fields.

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