BEAM DYNAMICS SIMULATION FOR EPU200 IN TPS

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Abstract

The Taiwan Photon Source (TPS) is a low-emittance 3-GeV light source at Natioal Synchrotron Radiation Research Center. Five in-vacuum undulator beamlines were delivered to users on Sep. 22, 2016. To generate 10 ~ 500 eV photon with variuos polarizations, users proposed a new EPU : EPU200. In this paper, we present the preliminary results of beam dynamics simulation for EPU200.

INTRODUCTION

TPS [1] storage ring is composed of 24 DBA cells. There are 18 short straight sections (7m) and 6 long straight sections (12m) in storage ring. Three long straight sections are symmetrically configured as double mini-βy lattice [2]. The phase-I IDs, 7 in-vacuum undulators (IU) and 3 elliptically polarized undulators (EPU), were installed in the TPS storage ringe since 2015. Five in-vacuum undulator beamlines were delivered to users on Sep. 22, 2016. To generate 10 ~ 500 eV photon with various polarization, users proposed a new EPU: EPU200. The main parameters of EPU200 and phase-I IDs are listed in Table 1. Figure 1 shows the locations of EPU200, phase-I IDs, and 7 beamlines.

EPU200 is modeled by kickmap generated by RADIA [3]. The impact on beam dynamicas due to EPU200 was simulated by numerical tracking code TRACY-II [4]. The impact on emittance and energy spread was estimated by analytical formulas. Dynamic aperture (DA), frequency map analysis (FMA), momentum acceptance, Touschek lifetime are simulated by TRACY-II. The simulation conditions were set up by the following procedures. We used 72/96 (H/V) correctors to create an electron orbit which mimicked the electron orbit measured in real machine. By doing so it is equivalent to consider magnet misalignment and orbit correction.

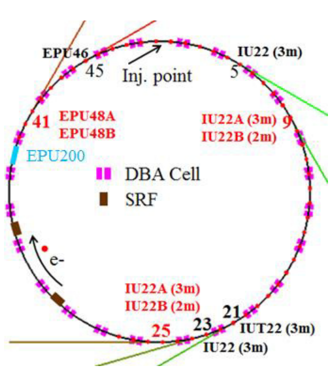

Figure 1: Locations of EPU200, phase-I IDs and 7 beamlines in TPS storage ring

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Table 1: Parameters for EPU200 and Phase-I IDs

	EPU200	IU22	EPU46	EPU48
Photon energy	0.01-0.6	1.25-20	0.28-2.0	0.22-2.0
[keV]	0.02-0.6		0.42-2.0	0.34-2.0
λu [mm]	200	22	46	48
Nperiod	19	140	82	67
By [T]	0.52	0.76	0.78	0.83
Bx [T]	0.35		0.52	0.55
Kymax	9.713	1.56	3.35	3.72
Kxmax	6.53		2.23	2.47
L [m]	3.8	3.57	3.89	3.436
Gap [mm]	29	7	14	13

EPU200 KICKMAP

The horizontal and vertical kick map of EPU200 are shown in Fig.2, depicted as function of transverse position x and y in unit of mm. The vertical axis is kick angle in unit of T^2m^2. The kick maps for EPU200 are calculated for transverse positions of x = -30 ~ +30 mm and y = -6.5 ~ +6.5 mm by RADIA [3].

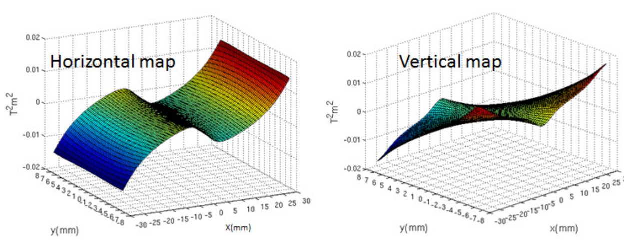

Figure 2: Horizontal and vertical kick map of EPU200 (gap = 29 mm, phase = 0).

LINEAR OPTICS DISTORTION

The peak field of EPU200 at gap 29 mm is about 0.5 Tesla. It is a weaker field undulator compared to the ring dipole (1.1908 Tesla). Figure 3 shows the beta beat due to EPU200 (gap at 29 mm, phase at 0 mm). As depicted in Fig. 3, the magnitude of beta beat is within 1% and 0.2 % in the horizontal and vertical plane respectively. It is a minor effect. Hence, we do not perform optics correction when calculating the dynamic aperure and frequency map.

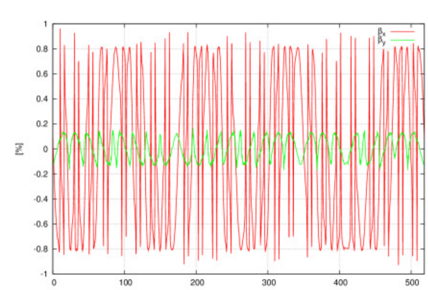

Figure 3 : Beta beat due to EPU200 (gap = 29 mm, phase = 0).

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PHYSICAL APERTURE AND SIMULATED ELECTRON ORBIT

The physical aperture used in simulation is the minimum of ID's gap or vacuum chamber. The vertical aperture of standard straight section is -10 ~ +10 mm. In ID sections the aperture is -3.5 ~ +3.5 mm for IU22, -3.5 ~ +3.5 mm for EPU48 and EPU46, -6 ~ +6 mm for EPU200. The vertical aperture for arc region between two bending magnets is -15 ~ +15 mm. The horizontal aperture of the whole ring is -34 ~ +34 mm. Figure 4 shows the vertical aperture used in the TRACY-II simulation.

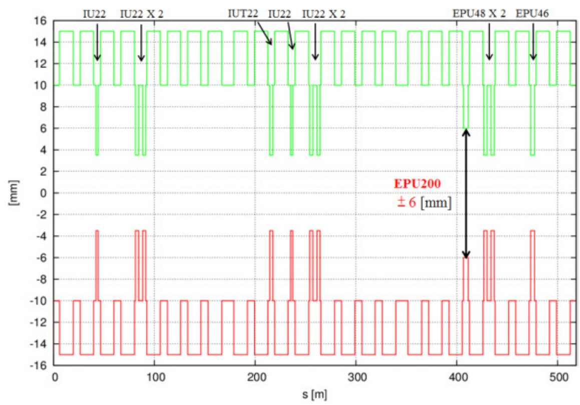

Figure 4 : Vertical aperture in simulation.

Since TPS was commissionied successfully [5-6], only one possible configursation of magnet misalignment and multipole errors need to be considered. The electron orbit in daily operation is corrected by 72/96 (H/V) correctors and BBA. Storage ring lattice is calibarted by LOCO. Hence, we use 72/96 (H/V) correctors to mimic the measured electron orbit of the real machine. This is equivqlent to consider magnet misalignment and orbit correction. Figure 5 shows the simulated orbit.

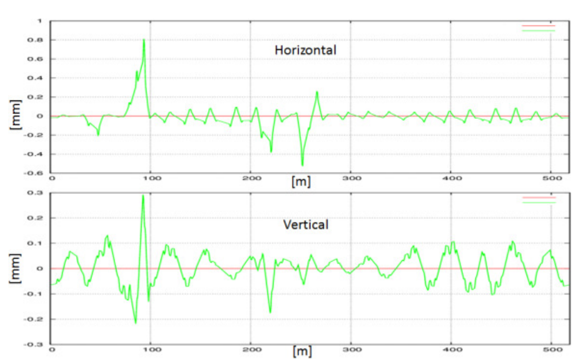

Figure 5 : Simulated electron orbit by 72/96 (H/V) correctors.

The simulated electron orbit is obtained by using SVD technique. We have the orbit response matrix of model lattice and the electron orbit of real machine. The corrector strength is derived from the equation : X = RC, X is the electron orbit of the real machine, R is the orbit response matrix, C is the corrrector strength (unknown). The corrector strength is extracted by using the above equation and SVD technique.

DYNAMIC APERTURE AND FREQUENCY MAP ANALYSIS

The dynamic aperture (DA) is defined as the maximum transverse region in which particle survive after 1000-turn tracking. On-momentum and off-momentum DA will affect the beam injection and lifetime respectively. Frequency map analysis (FMA) can assist us to identify the dangerous resonance lines. Comparing Figs. 6 and 7, EPU200 is shown to cause minor tune shift (on-axis) about 0.0017 and 0.0004 for the horizontal and vertical plane respectively.

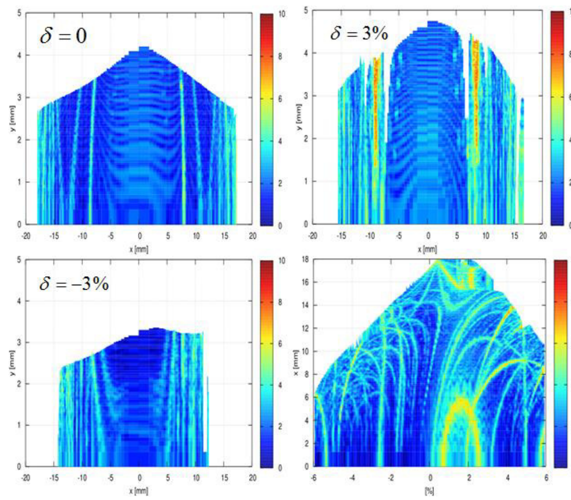

Figure 6: DA (on-momentum and off-momentum) for ideal lattice without EPU200 , tracked at center of long straight with $\beta_x = 10$ m and $\beta_y = 6$ m, aperture included.

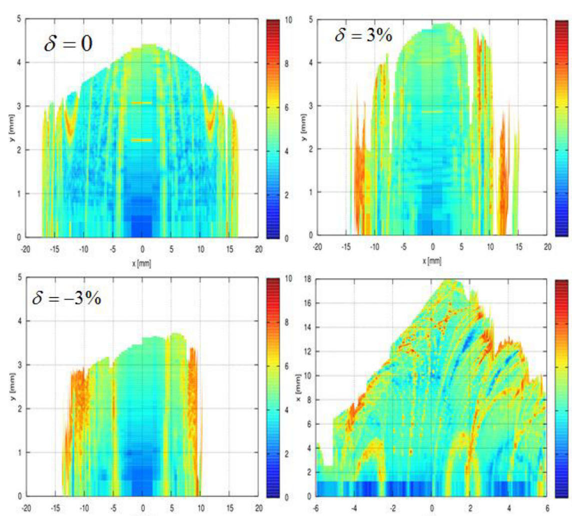

Figure 7: DA, tracked at center of long straight with $\beta_x = 10$ m and $\beta_y = 6$ m, considering 1% emittance coupling, multipole errors, physical aperture and kick map of EPU200 (gap = 29 mm, phase = 0).

MOMENTUM ACCEPTANCE AND TOUSCHEK LIFETIME

The momentum acceptance of the TPS storage ring is calculated at each location of lattice element by searching the maximum momentum deviation in which particle survive after 1000-turn particle tracking. In each location of lattice element, momentum deviation is varied from 0.025 to 0.075 with incement of 0.001 till particle is lost. In each increment of momentum deviation, particle is tracked 1000 turns. Fig. 8 shows calculated momentum acceptance.

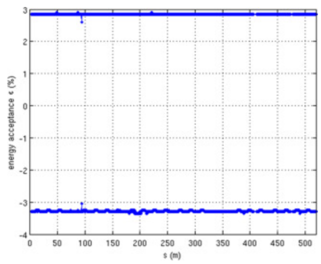

Figure 8: Momentum acceptance versus longitudinal position, considering 1% emittance coupling, multipole errors, physical aperture and kick maps of EPU200 (gap = 29 mm, phase = 0).

Touschek lifetime is calculated by Bruk formula [7]. It states as:

$$\frac{1}{\tau} = \frac{r_e^2 cN}{8\pi\gamma^3\sigma_s}\frac{1}{L}\oint \frac{F(x)}{\sigma_x(s)\sigma_y(s)\sigma_{x'}(s)\varepsilon_{ac}^2(s)}ds$$

N is the number of electron per bunch, r_e is classical electron radius, c is the speed of light, γ is the relativistic Lorentz factor, L is ring circumference, σ_s is bunch length (rms), $\sigma_x(s)$ and $\sigma_y(s)$ are horizontal and vertical beam size (rms) respectively, $\sigma_{x'}(s)$ is horizontal beam divergence (rms).

$$F(x) = -\frac{3}{2}e^{-x} + \frac{x}{2}\int_x^\infty \frac{\ln u}{u}e^{-u}du + \frac{(3x - x\ln x + 2)}{2}\int_x^\infty \frac{e^{-u}}{u}du$$

$x = (\varepsilon_{ac}(s) / \gamma\sigma_{x'}(s))^2$, $\varepsilon_{ac}(s)$ is momentum acceptance.

The Touschek lifetime is about 13 hours at RF gap voltage of 3.5 MV, bunch current is 0.5 mA per bunch, considering 1% emittance coupling, multipole errors, physical aperture and kick map of EPU200 (gap = 29 mm, phase = 0).

ENERGY SPREAD AND EMITTANCE

The impact on energy spread and emittance due to EPU200 are estimated by the following formulas [8]:

$$\left(\frac{\sigma_E}{E}\right)^2 = \left(\frac{\sigma_E}{E}\right)_0^2 \begin{cases} (1+\frac{8}{3\pi}\frac{\rho_0}{\rho_w}\frac{U_w}{U_0})(1+\frac{U_w}{U_0})^{-1} & (planer) \\ (1+\frac{\rho_0}{\rho_w}\frac{U_w}{U_0})(1+\frac{U_w}{U_0})^{-1} & (helical) \end{cases}$$

$$\frac{\varepsilon_x}{\varepsilon_{x0}} = \begin{cases} (1+\sum_w \frac{8}{3\pi f_h}\frac{\rho_0}{\rho_w}\frac{U_w}{U_0})(1+\sum_w \frac{U_w}{U_0})^{-1} & (planer) \\ (1+\sum_w \frac{1}{f_h}\frac{\rho_0}{\rho_w}\frac{U_w}{U_0})(1+\sum_w \frac{U_w}{U_0})^{-1} & (helical) \end{cases}$$

U_0 and U_w are the energy loss per turn in ring dipole and undulator respectively. ρ_0 and ρ_w are the bending radii of ring dipole and undulator respectively, f_h is the ratio of the average H-function in ring dipole to the maximum of the H-function at the ID end. These two formulas for energy spread and emittance hold for weaker field undulator, which means $B_w < (3\pi f_h) B_0$, B_0 and B_w are the magnetic flux densities of ring dipole and undulator respectively. The impact of EPU200 on the energy spread and emittance is minor reduction ratio aobut 0.9975 and 0.9962 respectively.

SUMMARY

To evaluate the beam dynamics effect of EPU200 in the TPS storage ring, we calculate the dynamic aperture, frequency map analysis, momentum acceptance and Touschek lifetime, energy spread and emittance by TRACY-II simulations. According to the preliminary simulation results, we think the impact on the beam dynamics in TPS storage ring due to EPU200 can be compensated. When we commission the EPU200, we will need to build the COD feed-forward table, tune feed-forward table, and coupling feed-forward table to preserve the performance of light source.

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