INJECTION SIMULATIONS FOR TPS STORAGE RING

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Abstract

We present injection simulations for the TPS (Taiwan Photon Source) storage ring. The baseline lattice of TPS storage ring is a 6-fold structure with 24 double bend cells [1]. The three double-mini-β_y lattice [2] with insertion devices (IDs) will be applied for user mode operation. The Tracy-2 [3] program is used to simulate the particle motion in 6-D phase space. We adopt lattice models which include errors of alignments and magnet fields. The particle loss due to scraping by chamber limit is recorded in Tracy-2 simulation. We can estimate the particle loss distribution and provide a reference for the shielding design accordingly.

INTRODUCTION

The TPS storage ring will operate in the top-up mode to provide a stable and low emittance X-ray light source. The efficiency of injection process is required to be above 80% in order to minimize the radiation levels. The layout of off-axis injection for TPS storage ring is shown in Fig. 1. The nominal parameters of injection kickers, DC and pulsed septa are listed in Table 1. There is no magnet between adjacent kickers. The closed orbit bump for the stored beam is created by four fast kickers. The kickers are driven by half-sine pulse with duration of about two revolution periods.

The thickness of septum wall is 3 mm. Considering the mechanical tolerance of septum wall and the size of injected beam, we set the ideal launching condition for an injected beam center in 6-D phase space is $(x, x', y, y', \Delta E/E, c\tau) = (-24.5 \text{ mm}, 0, 0, 0, 0, 0)$ with respect to the center of stored beam pipe and RF bucket. A multiparticle beam of Gaussian distribution is used for tracking simulations of injection process. Figure 2 shows an example of injection simulation for a multiparticle beam in the horizontal phase space. To obtain a realistic simulation of injection process, we include various engineering errors.

INJECTION SIMULATIONS

The simulations are done in the frame of Tracy-2 program. We include the multipole field errors of magnets in lattice model according to the spec. The alignment errors of magnets and girders are also included according to Table 2. The emittance coupling caused by rotation errors we set is about 2%, which is estimated by the modified "Coupling_Edward_Teng" function [4]. There are 168 beam position monitors (BPMs) and horizontal/vertical correctors

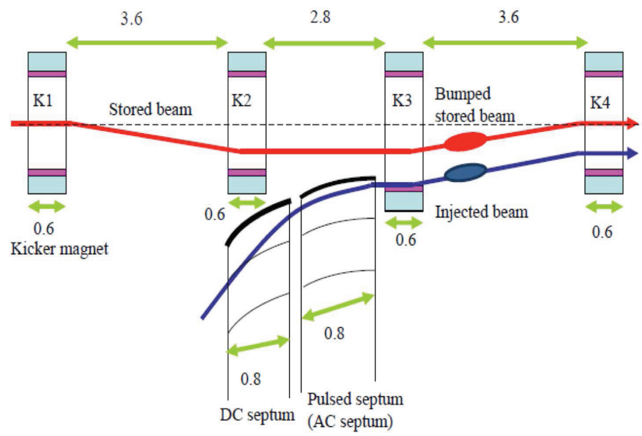

Figure 1: The layout of off-axis injection for TPS storage ring, in the units of meters.

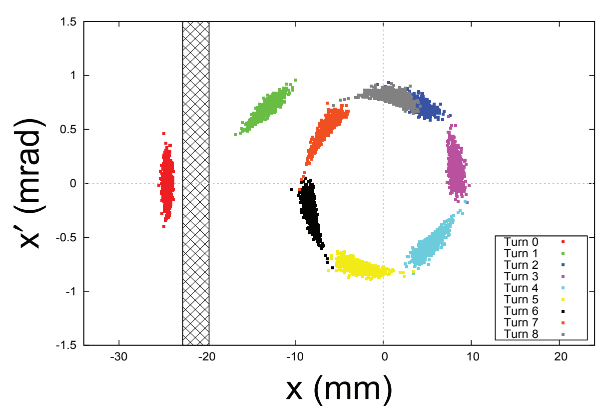

Figure 2: The injection simulation for a multiparticle beam in horizontal phase space at injection point. The first eight turns of particles tracking are shown. The black cross lines represent the septum wall with a thickness of 3 mm.

used to correct the orbit distortions. The orbit distortions after corrections are about a few micro-meters from ideal trajectory, if we do not consider BPM or corrector errors. The IDs are modeled by kick maps which are generated by RADIA [5]. We set the chamber limits for storage ring in different sections according to the engineering design. Note that the physical apertures for IDs in vertical direction are narrowed to ± 3.5 or ± 4.5 mm.

The strength for an injection kicker as a function of time is $K(t)$:

$$K(t) = A(1 + \delta_A)\cos(\frac{t + \delta_t}{T} \times \frac{\pi}{2}) \quad (1)$$

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Table 1: Nominal Parameters of Injection Kickers, DC and Pulsed Septa

Parameters	Kicker (×4)	DC Septum	Pulsed Septum
Length (m)	0.6	0.8	0.8
Bending angle (mrad)	4.5	55.5	55.5
Field strength (T)	0.075	0.694	0.694
Half-sine width (μs)	5.5	...	300

Table 2: TPS Storage Ring Alignment Errors

Element	Alignment error in r.m.s. $\Delta x/\Delta y/\Delta\theta_s$ (mm/mm/mrad)
Girder	0.1/0.1/0.1
Quadrupole on girder	0.03/0.03/0.1
Sextupole on girder	0.03/0.03/0.1
Dipole	0.5/0.5/0.5
Injection kicker	0/0/0.04

where $A = 4.5$ (mrad) is a nominal value of kicker strength, $T = 5.5/2$ (μs) is the duration of half-sine pulse divided by two. δ_A and δ_t are pulse amplitude noise and time jitter with $1\sigma = 0.1\%$ and $1\sigma = 2$ (ns), respectively. The circumference of TPS storage ring is 518.4 m. So the kicker strength after a revolution of an injected beam is reduced to about 2.5 (mrad). There are 10 random lattice models with different errors of multipole fields and alignments for magnets, plus different noises for injection kickers, used for simulations.

We use 1,000 particles to represent an injected beam bunch and track these particles in 6-D phase space for a thousand turns. The size of an injected beam is dependent on parameters at the exist of transfer line from booster to storage ring. The twiss parameters at the exist of transfer line are $\beta_{xi} = 2.055$ (m), $\beta_{yi} = 6.18$ (m), $\alpha_{xi} = 0$ and $\alpha_{yi} = -0.132$. Taking into account all possible engineering errors in the transfer line, we conservatively set the emittance for an injected beam is $\epsilon_{xi,yi} = 31.3$ (nm-rad). A multiparticle beam of Gaussian distribution is generated according to [6]:

$$\begin{aligned} x &= \sqrt{-2\epsilon_{xi}\beta_{xi}\ln R_1}\cos 2\pi R_2, \\ x' &= -\sqrt{\frac{-2\epsilon_{xi}}{\beta_{xi}}\ln R_1}(\sin 2\pi R_2 + \alpha_{xi}\cos 2\pi R_2) \end{aligned} \tag{2}$$

where R_1 and R_2 are random numbers and uniformly distributed in the range $0 < R_{1,2} \leq 1$. The beam distributions in longitudinal phase space are also assumed as Gaussian with mean's $= 0$ and $1\sigma = 0.1\%$ for energy spread and $1\sigma = 10$ (ps) for the fluctuation in longitudinal position.

The errors of transfer line from booster to storage ring or septa would cause the variations of launching condition for an injected beam in transverse phase space. We scan the launching condition for an injected beam on x-, x'-, y- and y'-direction, check their capture efficiencies and record the particle loss due to scraping by chamber limit. Figure 3 shows the dependences of capture efficiencies for an injected beam on four launching directions. To estimate the particle loss distribution, we sum up the lost particle information from 10 random model simulations, and calculate the probability of particle loss due to scraping on each element in the ring. The results are shown in Fig. 4.

DISCUSSIONS

We have performed injection simulations for an beam into TPS storage ring and their tolerance studies in beam launching conditions. Table 3 summarizes the range of an injected beam deviation from ideal launching condition in order to have larger than 80% efficiency. We assume there are no correlations between the deviations of beam launching conditions on x-, x'-, y- and y'-direction. It can be further studied by randomly selecting an injected beam center with non-zero Δx, $\Delta x'$, Δy and $\Delta y'$ for simulations. The probability of particle loss due to scraping in the ring is relatively large at the port 5, 9, 21, 25, 41 and 45, as shown in Fig. 4. This is because the physical spaces for IDs are limited in vertical direction. We do not yet consider the leakage of magnet field from septa in simulations. The errors of synchronisation for four injection kickers should also be included. These can be done in future once we obtain the measured data.

Table 3: Injected Beam Deviations

Deviation variable	Range of >80% efficiency
Δx (mm)	$[-3.4, 0]$
$\Delta x'$ (mrad)	$[-0.6, +0.6]$
Δy (mm)	$[-3, +3]$
$\Delta y'$ (mard)	$[-0.4, +0.4]$

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ISBN 978-3-95450-122-9

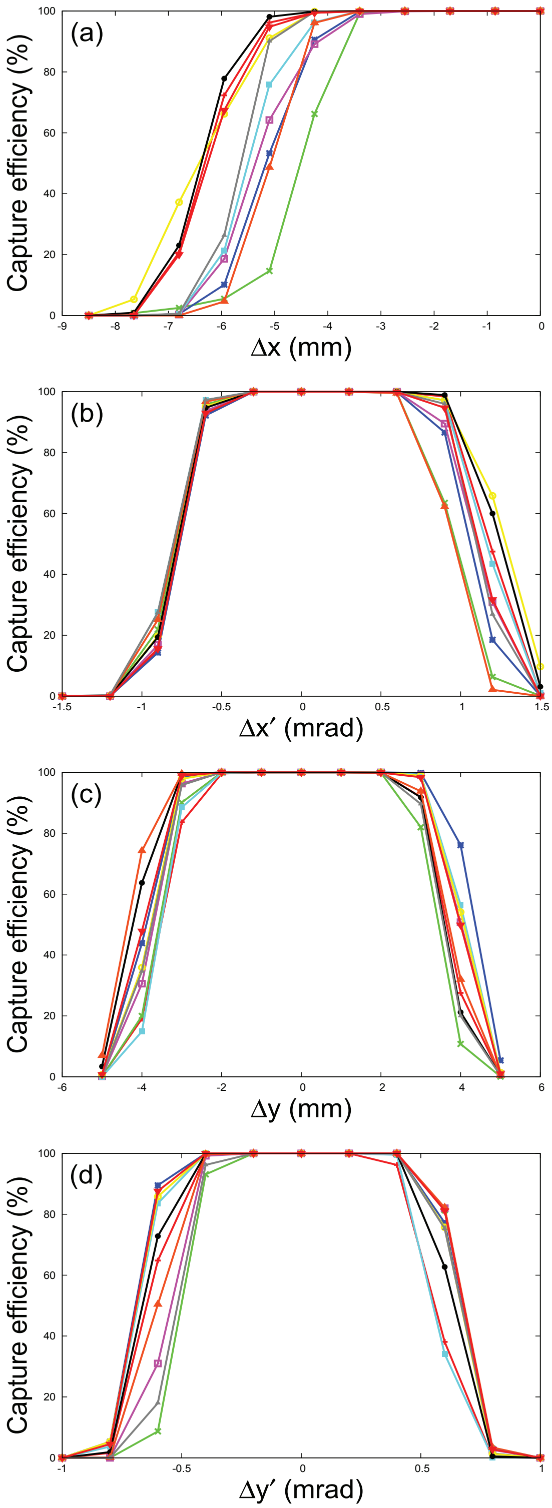

Figure 3: The capture efficiency vs. the deviation of launching condition for an injected beam on (a) x-, (b) x'-, (c) y- and (d) y'-direction. There are 10 random lattice models used for injection simulations.

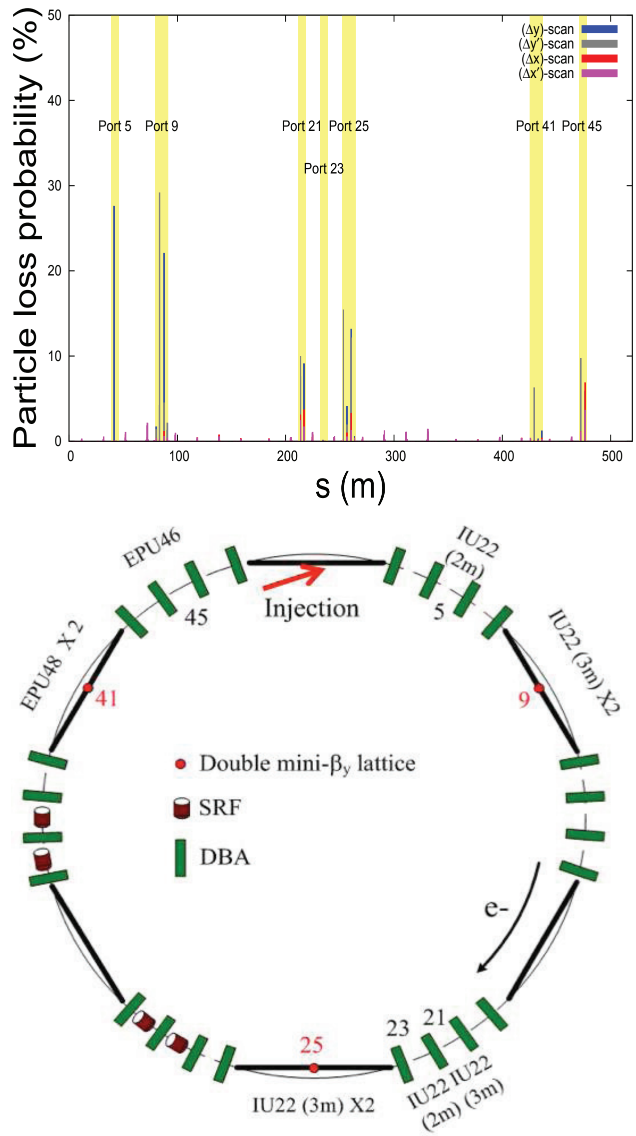

Figure 4: The particle loss distributions in TPS storage ring are shown in the upper plot. The locations of straight sections which contain IDs are marked as light yellow columns. Lower plot is the corresponding layout of TPS storage ring with port numbers which contain double-mini-β_y and IDs.