ACCELERATOR PHYSICS ISSUES FOR TPS

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Abstract

Taiwan Photon Source (TPS) is a 3 GeV low emittance 3rd-generation light source currently under construction at the NSRRC site in Taiwan. TPS consists of 24 double-bend cells and its circumference is 518.4 m. A 496.8-m booster with multi-bend structure is designed. In this paper, we present the accelerator physics issues including nonlinear optimization, Touschek lifetime estimation, orbit and coupling corrections, effects of insertion devices, impedance and instabilities, alterative lattice configurations and booster injector.

INTRODUCTION

TPS is situated at the same site of the 1.5 GeV Taiwan Light Source which has been in operation since 1993. The groundbreaking ceremony for the civil construction was held in February 2010, and user operations are scheduled in 2014.

The lattice design status of the TPS storage ring, booster ring and transfer lines were reported in [1~3]. In the first phase of operations, several in-vacuum undulators of 5 mm gap and a couple of EPUs will be installed. Superconducting RF system of 500 MHz will be used and Touschek lifetime estimation is fully studied. The top-up injection with injection interval of 2 minutes is the baseline design. Instabilities are investigated and cures are proposed. Some alternative optics configurations for special purposes are studied also.

LATTICE

The storage ring is with 24 DBA lattice cells and 6-fold symmetry. The machine functions are depicted in Fig. 1. Major parameters are listed in Table 1.

Eight families of sextupoles are employed to optimize the nonlinear beam dynamics. The tolerable multipole errors of magnets included in the simulations cause acceptable reduction of dynamic and momentum apertures. Figure 2 is the dynamics aperture with and without tolerable multipole field errors.

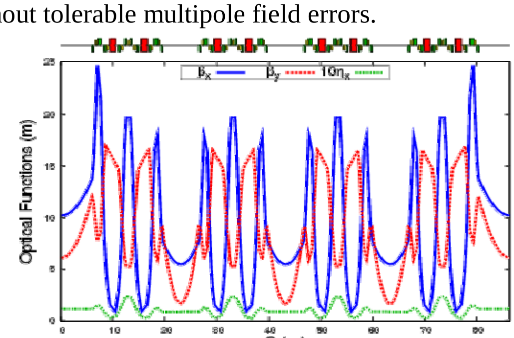

Figure1: Lattice optical functions of the TPS storage ring.

Table 1: TPS Major parameters

Circumference (m)	518.4
Energy (GeV)	3.0
Horizontal emittance (nm-rad)	1.6
Vertical emittance (nm-rad)	0.016
Average beam current (mA)	400
Straight section	12m*6+7m*18
Radio frequency (MHz)	499.654
Harmonic number	864
SR loss/turn, dipole (MeV)	0.853
Mom. compaction (α_1, α_2)	2.4E-4, 2.1E-3
Damping time $\tau_x/\tau_y/\tau_s$ (ms)	12.2/12.1/ 6.0
Natural chromaticity (ξ_x/ξ_y)	-75 / -26

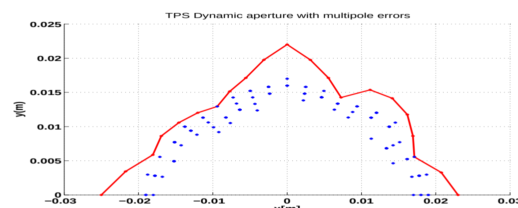

Figure 2: Dynamic aperture at the center of long straight without (red line) and with (blue point) multipole field errors in the magnet tolerance specifications.

ORBIT AND COUPLING

The error sources of orbit are controlled to minimize the closed orbit distortions (COD). The rms error tolerances are as follows: magnet to girder 0.03 mm, girder to girder 0.1 mm, dipole field 0.001, roll 0.1 mrad and BPM 0.1 mm. The rms COD is 3.8 mm and 2.2 mm in the horizontal and vertical plane, respectively. With all correctors (embedded in the sextupoles), i.e. 168 in each plane, one can reduce COD down to 0.1 mm rms w.r.t. ideal orbit for the case without BPM beam based alignment (BBA). With BBA, the residual orbits are around 10 μm rms w.r.t. quadrupole centers [4]. The maximum corrector strength is reduced to 0.5 mrad.

We plan to have 96 skew quadrupoles (also embedded in the sextupoles) in the whole ring to control emittance coupling so that the ratio can be reduced to less than 1% in the case of typical coupling errors.

INSERTION DEVICE AND TOUSCHEK LIFETIME

More than 20 straights can be used for the accommodation of insertion devices to generate high brilliance synchrotron light sources. In the first phase of operations, we will install five in-vacuum undulators, two EPUs, etc.

By using all quadrupoles for the optics and phase advance correction in the presence of IDs, the beta-beats can be corrected to less than a few % and tunes and phase advances are restored. The nonlinear kick map generated from RADIA (ESRF version) code is used for the dynamic tracking with TRACY-II (Soleil version). We obtain the on-momentum dynamic aperture tracking and the corresponding frequency map for the condition with ID chamber aperture limits, 1% emittance coupling and mutipole errors shown in Figs. 3 and 4.

As given in Table 1, large α_2 in the nominal lattice configuration will induce nonlinear longitudinal motion and distortion in longitudinal phase space. The energy acceptance simulated with TRACY-II and corresponding Touschek lifetime are given in Figs. 5 and 6 [5].

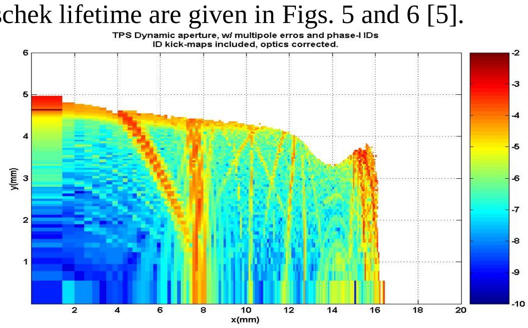

Figure 3: Dynamic aperture (on-momentum) at long straight center with phase-I IDs, including multipole errors, 1% emittance coupling, ID kick maps, and ID chambers. Optics corrected.

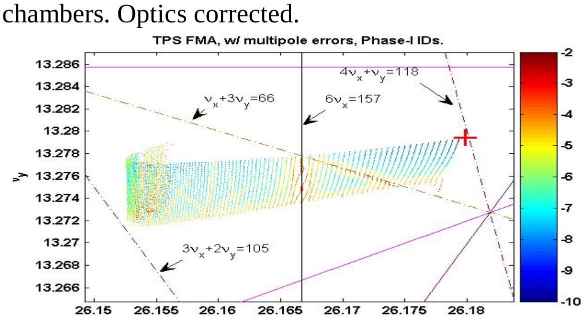

Figure 4: Corresponding frequency map with phase-I IDs, including multipole errors, 1% emittance coupling, ID kick maps, and ID chambers. Optics corrected.

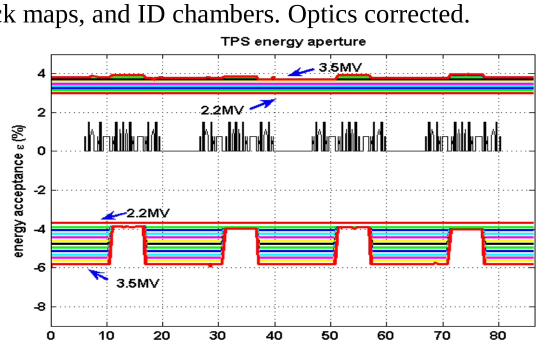

Figure 5: Energy aperture for RF gap voltage from 2.2 MV to 3.5 MV with vertical ID chambers, multipole errors and 1% betatron coupling. 6-D particle tracking is performed with TRACY-II. Chromaticities are 2.0 in both planes.

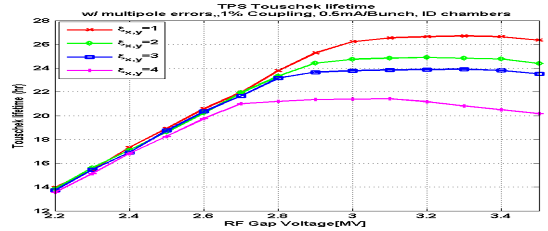

Figure 6: Touschek lifetime as functions of RF gap voltages and chromaticity settings using TRACY-II and Bruck formula. Bunch current 0.5 mA, ID vertical chamber inner aperture 7 mm, multipole field errors and betatron coupling 1% assumed in the simulations.

ALTERNATIVE OPTICS

TPS lattice can be configured to several different modes. The strong field IDs can cause increase of emittance and energy spread for 1.6 nm-rad mode. It can be operated at slightly higher emittance in which dispersion functions in the straight sections can be reduced and the emittance changes due to strong field IDs can be minimized. The low alpha (momentum compaction) mode (as low as 1e-5) provides short bunch length in a few ps with the optics shown in Fig. 7. However, the second-order alpha needs to be reduced to near zero. The high/low betax in the straights in Fig. 8 provides beam size and beam divergence control for different experimental properties.

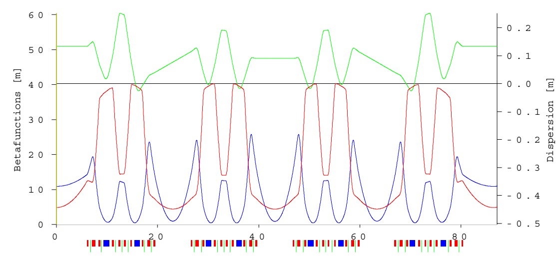

Figure 7: Low alpha lattice: α_1 = 7.3e-6, ε_x= 2.8 nm-rad.

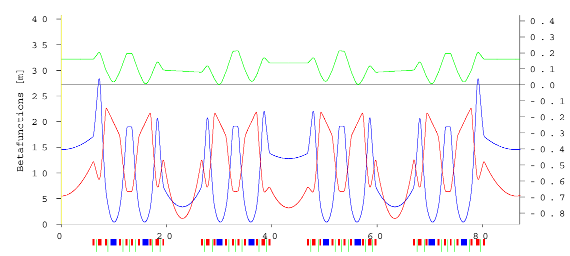

Figure 8:High/low betax lattice option. ε_x= 1.6 nm-rad.

The double vertical waist in long straight is for two mini-gap IDs. There are two different double vertical mini-betay configurations, one with mirror symmetry w.r.t. straight middle and the other with alpha focusing effect [6]. Figure 9 shows the optics of the symmetry case and Fig. 10 is the dynamic aperture tracking result with two 3.5 m EPUs and 1% coupling and magnet multipole errors. Touschek lifetime calculated from the momentum acceptance tracking with TRACY-II for such two EPUs and other phase-I IDs is more than 15 hours.

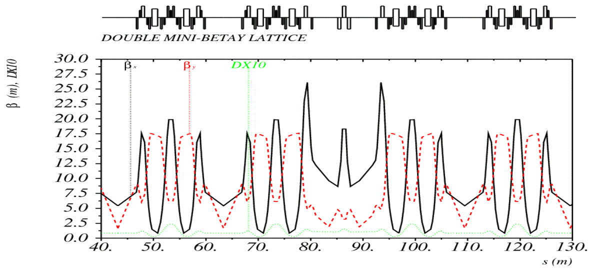

Figure 9: Double mini-betay lattice functions of the symmetry case.

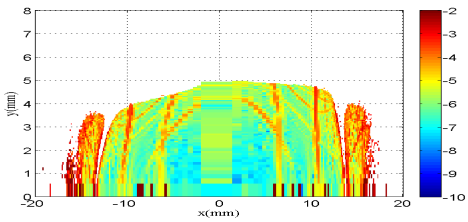

Figure 10: For symmetry case double mini-betay lattice, DA (on momentum) tracked at one normal long straight center (β_x=10m, β_y=6m) with 1% coupling and multipole errors and two EPU48s.

COLLECTIVE EFFECTS

For the 400 mA multi-bunch operation, a train of 800 bunches with 0.5 mA per bunch and with gaps of 64 empty buckets help reduce the slow ion trapping instability. The fast-ion instability can be minimized with low vacuum pressure, however a transverse damping system is required. Beam lifetime is long enough so that the top-up injection interval can be in 2 minutes and current stability is better than 1%.

Damped higher-order modes in the superconducting rf cavities can avoid longitudinal coupled-bunch instabilities. The broad-band impedances and loss factors for all components are simulated using 3-D code GdfidL. The total longitudinal broad-band impedance is 0.37Ω. The longitudinal single-bunch microwave instability occurs around 2 mA bunch current from the code ELEGANT (by M. Borland) and Boussard criterion as shown in Fig. 11. The pseudo-Green's function of wake potentials of all vacuum components from GdfidL and using Piwinski formula for resistive-wall potential is used for ELEGANT inputs. At high bunch current, the sawtooth type oscillations can be observed in the simulations [7, 8].

Transverse coupled-bunch instabilities due to rf cavities are also suppressed but coupled-bunch instabilities due to resistive-wall impedance can occur at low beam current and small chromaticity. Thus, we require a transverse feedback system for the stable beam operations. The head-tail instability and transverse mode-coupling instability thresholds are much higher than the nominal operation bunch current.

The coherent synchrotron radiation induced instability is estimated with analytical formula and also simulated with ELEGANT. It is found there is no such instability at nominal operation bunch current of < 2 mA.

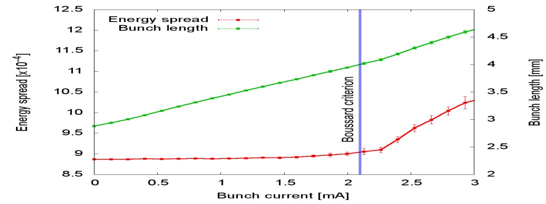

Figure 11: Longitudinal single-bunch microwave instability occurs around 2 mA bunch current simulated from the code ELEGANT and calculated with Boussard criterion (blue bar).

BOOSTER INJECTOR

The injector consists of a 150 MeV linac and a 3 GeV booster of 496.8 m. The booster lattice has six super-periods, each containing 7 modified FODO cells and two matching cells. Combined function magnets are used in the booster lattice to reduce number of magnets. The natural horizontal emittance is 10 nm-rad. The energy loss per turn at 3 GeV is 586 keV. Five-cell PETRA cavities of 500 MHz will be used. Good beam dynamics behavior is shown in the dynamic tracking. The booster ramping is at 3 Hz repetition rate. Figure 12 shows the lattice optical functions.

The accelerator physics issues such as closed orbit correction scheme, effects due to mutipole field errors, eddy current effect, emittance and energy spread evolutions during 3 Hz ramping, etc., are fully investigated and necessary measures are implemented [2].

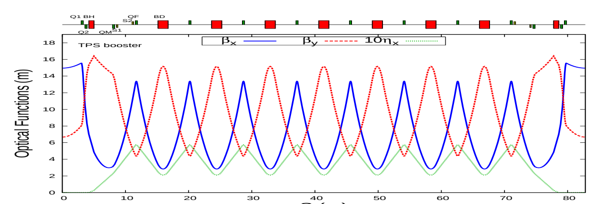

Figure12: Lattice optical functions of the TPS booster ring.

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