PROGRESS REPORT OF TPS LATTICE DESIGN

C.C. Kuo, H.P. Chang, H.C. Chao, P.J. Chou, G.H. Luo, H.J. Tsai
National Synchrotron Radiation Research Center, Hsinchu 30076, Taiwan

Abstract

Current lattice design status of the TPS 3 GeV synchrotron light source is reported. The updated design parameters of the storage ring and injector booster are given. Some beam dynamics issues are discussed.

INTRODUCTION

The lattice design work of the 3 GeV Taiwan Photon Source (TPS) has been reported in the past years.[1] The progress of the lattice design in storage ring is described in this paper and booster injector and two transfer lines are given in these proceedings.[2,3] The construction of conventional facility is expected to start within one year and beam commissioning will be in year 2014.

STORAGE RING DESIGN

The storage ring has 24 DBA lattice cells and the emittance is 1.6 nm-rad. It is a 6-fold symmetry configuration. Each DBA cell contains two 1.1 m dipoles, two 60 cm quadrupoles, eight 30 cm quadrupoles, and seven 25 cm sextupoles. The lattice optical functions are depicted in Fig. 1, and the major lattice parameters are listed in Table 1.

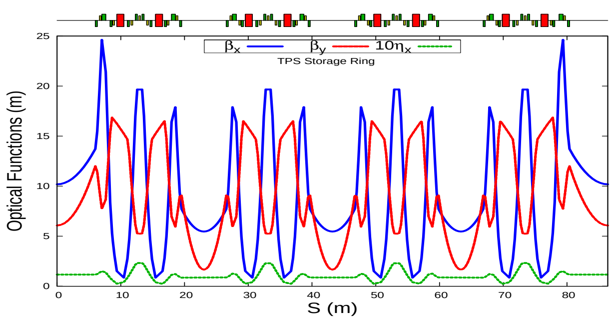

Figure 1: Lattice optical functions of the TPS storage ring.

DYNAMIC AND ENERGY APERTURE

The natural chromaticities of the TPS lattice are large and can be corrected to small positive settings with the help of strong sextupoles. We use an 8-family sextupole scheme, including chromatic correction sextupoles and associated harmonic sextupoles to optimize dynamic and energy apertures. Acceptable dynamic and momentum apertures are obtained with reasonable sextupole strengths for chromaticities at (+5,+5). Figure 2 shows the dynamic aperture for the cases with and without multipole errors, while the chromaticity is (+2,+2). The typical multipole errors are given in Table 2. By increasing the error strengths, say, an order of magnitude in quadrupoles and sextupoles, a large enough dynamic aperture is still attainable in the particle tracking.

Table 1: Major Parameters of the TPS Storage Ring

Circumference (m)	518.4
Energy (GeV)	3.0
Nat. emittance (nm-rad)	1.6
Revolution period (ns)	1729.2
Revolution freq. (kHz)	578.30
Radio frequency (MHz)	499.654
Harmonic number	864
SR loss/turn, dipole (MeV)	0.85269
Betatron tune (ν_x/ν_y)	26.18 /13.28
Mom. compaction (α_1, α_2)	2.4×10^{-4}, 2.1×10^{-3}
Natural energy spread	8.86×10^{-4}
Damping partition $J_x/J_y/J_s$	0.9977/1.0/ 2.0023
Damping time $\tau_x/\tau_y/\tau_s$ (ms)	12.20/12.17/ 6.08
Natural chromaticity (ξ_x/ξ_y)	-75 / -26

Table 2: TPS Storage Ring Multipole Error Normalized to Main Field at R=25 mm (in unit of 10^{-4})

Dipole	Systematic	Random
B1/B0	-	1
B2/B0	-5	2
B3/B0	-	2
B4/B0	5	5
B5/B0	-	1
B6/B0	-0.2	0.2
B8/B0	-0.6	0.6
Quadrupole		
A2/B1	-	3
B2/B1	-	2
B3/B1	-	3
B5/B1	1	0.5
B9/B1	1	0.5
B13/B1	-1	0.5
Sextupole		
B4/B2	-	3
B6/B2	-	0.5
B8/B2	-1	0.5
B14/B2	-1	0.5
B20/B2	-1	0.5

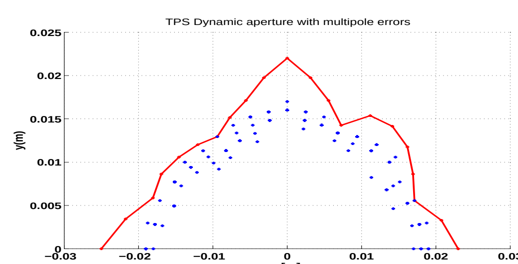

Figure 2: Dynamic aperture at the center of long straight with and without multipole errors.

Including longitudinal nonlinear motion due to large 2^{nd}-order momentum compaction factor, the lattice energy acceptance is in between -6% to 4%. With small vertical chamber size of 10 mm full gap and 1% betatron coupling, the energy aperture is simulated and Touschek lifetime is estimated for different RF voltage as given in Figs. 3 and 4.

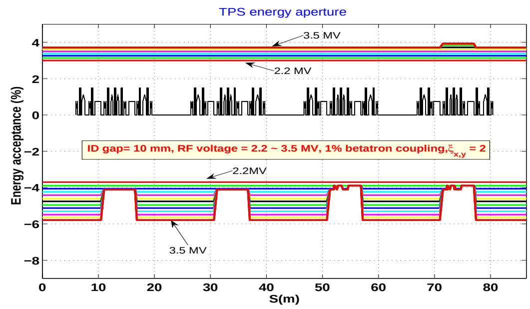

Figure 3: Energy aperture for RF gap voltage from 2.2 MV to 3.5 MV (larger aperture) with vertical chamber full gap of 10 mm in the ID straights and 1% betatron coupling. 6-D particle tracking is performed with TRACY-II. Chromaticities are set to 2.0 in both planes.

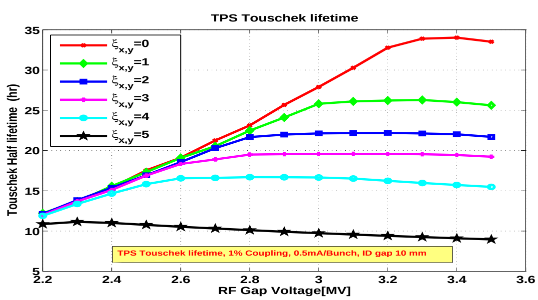

Figure 4: Estimated Touschek beam lifetime as a function of RF gap voltage for different chromaticity settings using TRACY-II and Piwinski formula. Bunch current 0.5 mA, ID vertical chamber size 10 mm and betatron coupling 1% assumed in the simulations.

CLOSED ORBIT AND COUPLING CORRECTION

The typical errors that generate closed orbit errors are very tight (rms errors: 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). With all correctors (built in the sextupoles), i.e., 168 in each plane, one can reduce residual orbits down to 0.1 mm rms w.r.t. ideal orbit for the case without BPM beam based alignment (BBA). The maximum corrector strength is 1.0 mrad. With BBA, the residual orbits are around 10 μm rms w.r.t. quadrupole centers. The maximum corrector strength is reduced to 0.5 mrad.

We also plan to have 96 skew quadrupoles (built in the sextupoles) in the whole ring so that emittance coupling emittance ratio can be reduced to less than 1% with skew strength no more than 0.2 T/m inside 25-cm sextupole magnets in the case of typical coupling errors (rms dipole roll 0.2 mrad, quadrupole roll 0.1 mrad, quadrupole and sextupole displacement 0.1 mm)

INSERTION DEVICE

More than 20 straights can be used for the accommodation of insertion devices. The phase I ID plan is still in discussion and will be decided by the end of this year. However, the beam dynamics effects are investigated. Using all quadrupoles for the optics and phase advance correction in the presence of IDs, the beta-beats can be corrected to less than 1% and tune and phase advance are restored. The nonlinear kick map generated from RADIA code is used for the dynamic tracking with TRACY-II. Putting a superconducting wiggler SCW60 (B_0=3.5T, λ=60mm, Npole=16) in one standard straight and located 1-m off straight center, for the case without any other errors in the simulation, we obtain the dynamic aperture tracking results and the corresponding frequency map with ID chamber aperture limits as shown in Figs 5 and 6. The destructive resonance lines and the reduction of the dynamic aperture can be revealed. Further optimization is needed for additional IDs.

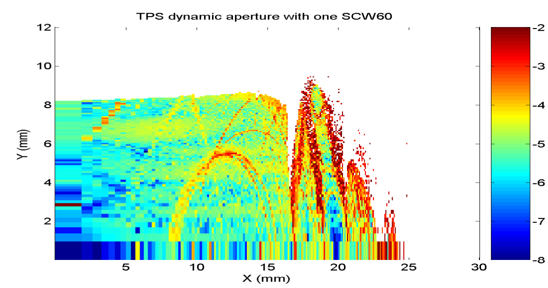

Figure 5: Dynamic aperture at long straight center with one SCW60 putting in one short straight (1-m off straight center). Chamber full size of the wiggler is 40 x 11 mm^2.

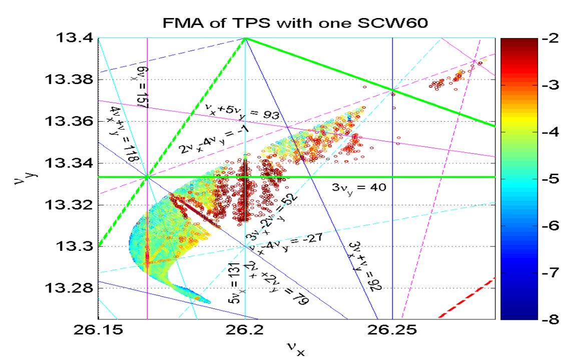

Figure 6: Corresponding frequency map with one SCW60 One of dangerous resonance lines is $2\nu_x+2\nu_y=79$ that causes a big dip.

INJECTOR

The injector consists of a 150 MeV linac and a 3 GeV booster of 496.8 m. This large booster is in the storage ring tunnel. The TPS booster design concept is similar to SLS and ALBA. The lattice is with six superperiods, each containing 7 modified FODO cells and two matching cells. Combined function magnets are used in the booster lattice to reduce number of magnets. There are seven 1.6 m and two 0.8 m combined function dipoles in each superperiod. The natural horizontal emittance is 10 nm-rad. The embedded sextupoles in the combined function magnets can correct chromacticity to (+1,+1). Separated function quadrupoles in the matching cells are used for optical matching and the independent sextupoles are used for chromaticity adjustment to compensate for the induced sextupole terms from the dipole chamber eddy current during energy ramping. Good nonlinear beam dynamics behavior is shown in the dynamic tracking. The booster ramping is at 3 Hz repetition rate and the emittance and energy spread can reach design values at extraction energy 3 GeV. Figure 7 shows the lattice optical functions and the booster parameters are given in Table 3.

The booster closed orbit correction scheme comprises of 60 BPMs, 60 horizontal and 36 vertical correctors. In each modified FODO cell, the horizontal corrector and BPM are placed near quadrupole so that these three different elements can share the same girder. The vertical correctors are near dipoles. Assume that 0.15 mm misalignment errors for quads and for dipole vertical plane, 0.2 mm for dipole horizontal plane and 0.2 mrad for all magnet roll errors, the rms CODs are 2.8/1.5 mm in x/y planes and maximum values are 10.5/8.1 mm in x/y planes. The corrected orbits can be reduced to less than 0.1 mm (rms) and maximum corrector strengths are less than 0.3 mrad in both planes. The number of BPMs and correctors can be reduced and still have acceptable residual orbit level. The magnet size is minimized and the bore radius is 18 mm for quadrupoles and sextupoles. With typical multipole errors and eddy current induced chromaticities are also included and corrected to (+5,+5), dynamic aperture as shown in Fig. 8 is large enough in comparison with the small chamber of 35 x 20 mm^2 elliptical full size.

Table 3: Major Parameters of the TPS Booster Ring

Injection energy (MeV)	150
Extraction energy (GeV)	3
Circumference (m)	496.8
Harmonic number	828
Betatron tune (ν_x/ν_y)	14.37/9.41
Energy Spread at 3 GeV	0.001
Nat. emittance at 3 GeV (nm-rad)	10.3
Mom. compaction	0.0025
Damping partition ($J_x/J_y/J_e$)	1.8/1.0/1.2
Damp. time ($\tau_x/\tau_y/\tau_e$) at 3 GeV (ms)	9.3/17.0/14.3
Nat. chromaticity ($\xi_x/\ \xi_y$)	-16.9/-13.3
SR loss/ turn at 3 GeV (keV)	586
Combined dipole magnet (B(T), B'(T/m), B''(T/m^2)) at 3 GeV	0.819, 1.73, 12.37
Combined quad magnet (B'(T/m), B''(T/m^2)) at 3 GeV	11.27, 25.75

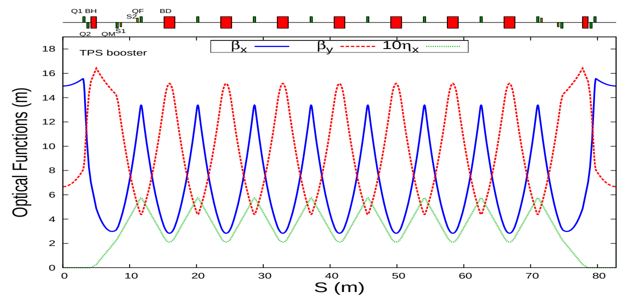

Figure 7: Lattice optical functions of the TPS booster ring.

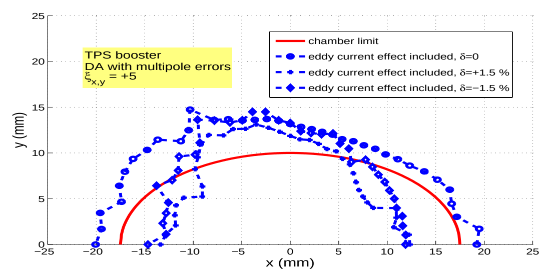

Figure 8: Dynamic aperture at the long straight center of the TPS booster with magnetic multipole errors. The bore radius of the quadrupoles and sextupoles is 18 mm.

TRANSFER LINES

Both linac to booster (LTB) and booster to storage ring (BTS) transfer lines have been designed. The linac energy is 150 MeV and this linac will be delivered by ACCEL Instruments GmbH in two years. The LTB consists of one 10 degree dipole and 10 quadrupoles for optical matching. Total length is less than 22 m.

Since both booster and storage rings are in the same tunnel, BTS line is as short as possible. Other than extraction and injection elements, there are two dipoles and seven quadrupoles for the optical matching. BTS line is less than 25 m. The associated diagnostic elements in both transfer lines are considered too. The injection and extraction elements, such as kickers, septa, are now in the final design phase.

SUMMARY

The accelerator lattice design works of the TPS, including storage ring, booster synchrotron, and two transfer lines, are in good progress. The developments of prototypes for the engineering subsystems are ongoing.

REFERENCE

[1] C.C. Kuo, *et al*, "Curent Status of the Taiwan Phtoton Source", EPAC08.

[2] H.C. Chao, *et al*, "Curent Design Status of the TPS 3 GeV Booster Synchrotron", these proceedings.

[3] P.J. Chou, *et al*, "Design Status of the transfer Lines in TPS", these proceedings.