DESIGN OF TAIWAN FUTURE SYNCHROTRON LIGHT SOURCE

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Abstract

We report updated design works for a new 3-3.3 GeV synchrotron light source with a high performance and low emittance storage ring, called Taiwan Photon Source (TPS). With its natural horizontal emittance less than 2 nm-rad and low emittance coupling, TPS will be able to provide an extremely bright photon beam to the demanding users, especially the x-ray community. The lattice type of the TPS is a 24-cell DBA structure and the circumference is 518.4 m. We present the lattice design, the accelerator physics issues and its expected performances.

INTRODUCTION

Almost two years ago, NSRRC Board of Trustee suggested us to propose another synchrotron light source with energy around 3 GeV to increase the research capacity, especially in the x-ray range. To fit into the existing site and to fulfil the user requirements, some configurations of the accelerator systems as well as the size of the storage ring have been discussed. One of the attractive configurations is a 24-cell ring with its circumference around 500 m. If we choose the booster synchrotron as the injector, we could have it either in the independent building or sharing the same tunnel as a concentric booster ring. Figure 1 is a layout of the 1.5-GeV and 3-GeV rings on the NSRRC site for the same-tunnel option of the TPS booster ring.

LINEAR LATTICE

A 24-cell DBA structure is presented. By allowing slightly positive dispersion in the long straights, the natural emittance of 1.7 nm-rad can be achieved. With a 6-fold symmetry configuration, the ring provides 6 long straights for injection, long IDs, and SRF modules. The optical functions of the lattice design are depicted in Fig. 2, and some of the major lattice parameters are listed in Table 1. With different kind of insertion devices, the calculated brilliance with 1% emittance coupling is plotted in Fig. 3.

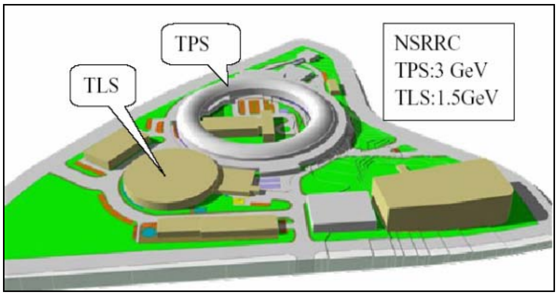

Figure 1: The TPS site plane.

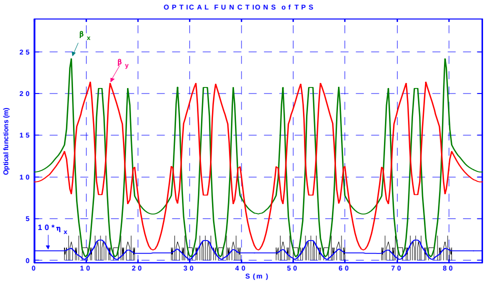

Figure 2: Optical functions of the TPS lattice.

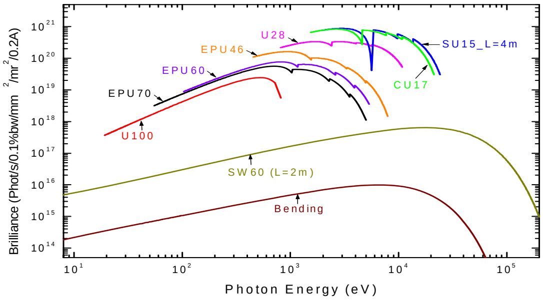

Figure 3: Brilliance of the TPS, 1% emittance ratio is assumed.

Table 1: Main lattice parameters of the TPS

Energy (GeV)	3.0
Beam current (mA)	400
Circumference (m)	518.4
Nat. emittance (nm-rad)	1.7
Cell / symmetry / structure	24 / 6 / DBA
β_x / β_y / η_x (m) LS middle	10.59 / 9.39 / 0.11
β_x / β_y / η_x (m) SS middle	5.56 / 1.23 / 0.086
RF voltage (MV)	3.5
Harmonic number	864
SR loss/turn, dipole (MeV)	0.98733
Straights	11.72m*6+7m*18
Betatron tune ν_x / ν_y	26.22 / 12.28
Synchrotron tune ν_s	5.6×10^{-3}
Bunch length (mm)	2.8
Dipole B/L (Tesla)/(m)	1.3789 / 0.95
Mom. comp. (α_1, α_2)	2.0×10^{-4}, 2.3×10^{-3}
Nat. energy spread σ_E	9.53×10^{-4}
Damping time ($\tau_{x,y,s}$) (ms)	10.5 / 10.5 / 5.25
Damping partition ($J_{x,y,s}$)	0.997 / 1.0 / 2.003
Nat. chromaticity ξ_x / ξ_y	-78.2 / -32.5

NONLINEAR BEAM DYANMICS

To correct chromacticity and to reduce the nonlinear effects we employ a sextuple scheme of 8 families. Fig. 4 shows the sextupole locations in a half superperiod. Mirror symmetry of the scheme is adopted. A sufficiently large dynamic aperture, in both on-energy and off-energy particle cases, is obtained to ensure efficient injection and reasonable lifetime. Figure 5 gives the tune shifts with horizontal amplitude, and Fig. 6 depicts the tune shifts with energy.

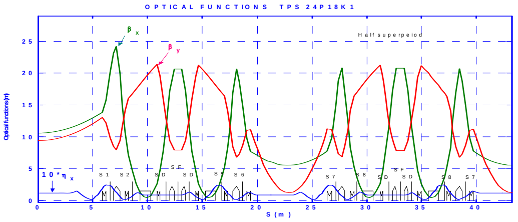

Figure 4: Sextupole scheme.

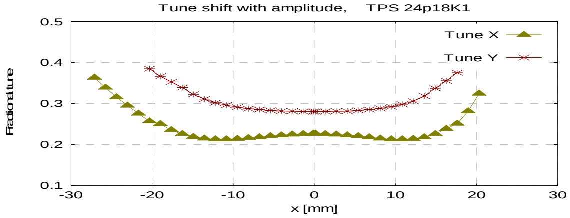

Figure 5: Tune shifts vs. horizontal amplitude.

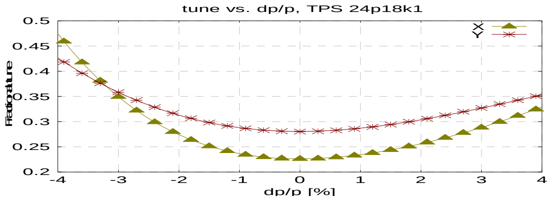

Figure 6: Tune shifts vs. energy deviation.

Figure 7 gives dynamic aperture for on-energy and off-energy (±3%) particles tracked for 1000 turns at the long straight center. Figure 8 is a dynamic aperture of on-energy particles tracked with 1000 turn using Tracy-2 and Fig. 9 is the corresponding frequency map analysis (FMA) plot. FMA reveals the resonance lines of the unstable particles. The most dangerous resonance lines are shown in the FMA plot. By changing the working point and optimizing sextupole strengths, we can avoid the dangerous resonance lines, even with small gap chambers.

Other nonlinear driving sources are from the imperfections of the magnetic field in dipole, quadrupole and sextupole magnets, and from insertion devices, etc. We take a set of typical multipole errors and we find that there is some reduction of the dynamic aperture but still good enough, as shown in Fig. 10.

There will be more than 21 insertion devices in the ring and their effects on the beam dynamics are also investigated. We simulated beam dynamics effects with 21 planned insertion devices in the TPS. The beam dynamics effects such as tune shift, emittance changes, etc. are studied, as given in Table 2, and the tracking results with these IDs show there are significant impacts on the dynamic aperture, but still acceptable. Small gap ID will limit the beam surviving space if the nonlinear behaviour is not optimized. Further study of the nonlinear optimization results in an acceptable dynamic aperture, shown in Fig. 11 and 12, assuming that the vertical half-gap of 5 mm in the ID straights and Touschek lifetime increase thereafter [1].

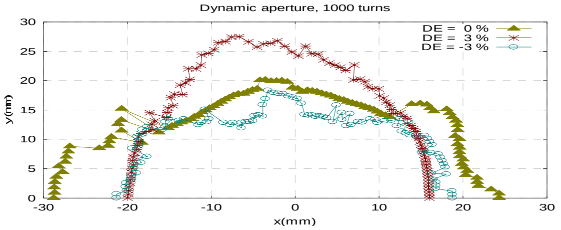

Figure 7: Dynamic aperture for on-energy and off-energy particles at long straight center.

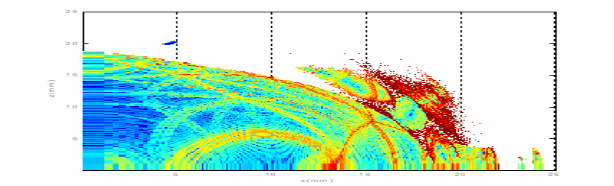

Figure 8: Dynamic aperture in the middle of long straight of the on-energy particles tracked 1000 turns using Taracy-2.

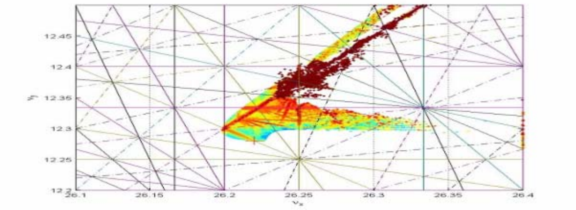

Figure 9: Frequency map analysis of the on-energy particles. The dangerous resonance lines such as $3\nu_x - 2\nu_y = 54$, $\nu_x + 2\nu_y = 51$ and $4\nu_x = 105$ are shown.

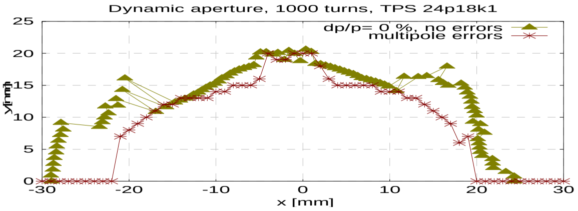

Figure 10: Dynamic aperture at long straight middle with and without multipole field errors.

Table 2: Some IDs effects.

ID Name	# of ID	$d\nu_y$	σ_E/E (10^{-4})	U_0 (MeV/turn)	ε_x (nm-rad)
w/o ID	0	0	9.5336	0.98733	1.7220
U100	1	0.005	9.44867	1.0131	1.7148
SW60	1	0.014	10.186	1.1267	2.1377
EPU46	1	0.003	9.4958	1.0022	1.7127
SEPU25	1	0.002	9.5131	1.0038	1.7221
ALL ID	21	0.158	9.5700	1.6846	1.9954

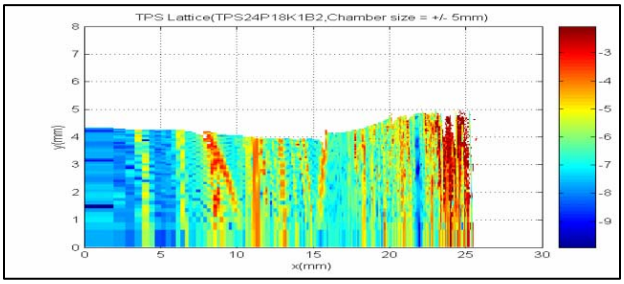

Figure 11: After re-adjustment of lattice and tracking with vertical half gap 5 mm, the dynamic aperture in the middle of long straight of the on-energy particles tracked 1000 turns using Tracy-2.

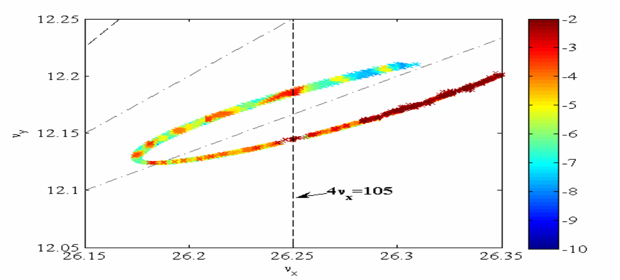

Figure 12: Corresponding frequency map analysis of Fig. 11.

CLOSED ORBIT CORRECTION AND COUPLING CONTROL

Closed orbit distortion (COD) due to alignment errors and dipole field errors are analyzed. It is found that the rms amplification factors due to rms quadupole misalignments are around 50 in both planes. For the designed girder support, the well pre-aligned magnets help to reduce the amplification factors down to around 30 and 10 in the horizontal and vertical plane respectively. Small alignment error down to 30 micron with respect to girder is our goal. Taking into simulations with a set of rms errors: quadudrupole misalignment w.r.t. girder 0.03 mm, girder misalignment 0.1 mm, dipole roll 0.2 mrad, girder roll 0.1 mrad, and dipole relative field error 0.001, we obtain the rms COD 3.66 mm in x and 2.28 mm in y respectively. Employing a COD correction scheme, we are able to correct it down to 50 micron rms in both planes [2].

The small emittance coupling as low as 1% is necessary to achieve high brilliance photon beam and we also analyze the contribution factors such as dipole and quadrupole roll errors, the off-center beam in quadrupoles and sextupoles, etc. It is found, with the typical roll errors as shown above, we need to correct orbit to the quadrupole and sextupole center down to less than 0.15 mm rms in order to get less than 1% emittance coupling, both for spurious vertical dispersion and betatron coupling contributions. Skew quadrupoles around the ring will be implemented to control the coupling as well [3].

GROUND VIBRATION

Vertical beam size in the low emittance and small coupling ring can be less than 10 micron. Stringent request for small vertical beam orbit fluctuation within sub-micron range is necessary to keep the photon flux stable. Therefore time dependent orbit error sources need to be controlled. One of these sources is the ground vibration. The maximum optics response to the plane ground wave in the vertical plane is less than 5 within 10 Hz and around 10 above 10 Hz with the help of girder support. Integrated vertical ground motion from the measurement in NSRRC site above 1Hz is around 100 nm and the simulated vertical beam motion above 1 Hz due to ground wave is around 300 nm [4]. Careful ground motion control is needed in the facility construction planning.

COLLECTIVE EFFECTS

With the superconducting cavities, no coupled bunch instabilities due to higher order modes of cavities are anticipated. However, the small gap insertion devices can induce transverse instabilities and the impedance budget is also very low to avoid microwave instabilities [5]. Lifetime is estimated to be larger than 10 hours for 5 mm vertical chamber size, 1% coupling, 1 nTorr vacuum, 0.6 mA bunch current and 3.5 MeV rf voltage.

BOOSTER INJECTOR AND OTHER RING OPTIONS

Booster synchrotron combined with a linac will be the injector. We can have concentric booster ring or separated one. Both types can have emittance lower than 20 nm-rad [6]. If the construction is at the current site, there will be civil engineering constraint. In that case, we are evaluating different configuration options such as 20-cell design or 24-cell but with different straight lengths, etc.

ACKNOWLEDGEMENTS

The authors would like to thank NSRRC director, K.S. Liang, for his continuous support and the valuable suggestions on the possible other options.

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