

OPTIMIZATION AND MEASUREMENTS ON THE DOUBLE MINI-BETAY LATTICE IN THE TPS STORAGE RING

M.S. Chiu[†], C.H. Chen, Y. C. Liu, F.H. Tseng, C.C. Kuo, H.J. Tsai, J.Y. Chen, K.H. Hu, P.C. Chiu, C.Y. Liao, Y.S. Cheng, T.Y. Lee, W.Y. Lin, B.Y. Chen, T.W. Hsu, P.Y. Huang, J.C. Huang, P.J. Chou

National Synchrotron Radiation Research Center, Hsinchu 30076, Taiwan

Abstract

The Taiwan Photon Source (TPS) is capable of operating in multi-bunch and single-bunch mode. To operate in a hybrid mode as requested by users, we developed a lattice with chromaticities of 0.8/2 (ξ_x/ξ_y) to provide higher single bunch currents. Beam dynamics simulations and lattice characterizations including dynamic aperture, frequency map analysis, tune shift with energy, tune shift with amplitude, and betatron coupling will be discussed in this report.

INTRODUCTION

The Taiwan Photon Source (TPS) [1] is a 3rd generation 3 GeV synchrotron light source. It delivers photon beams to users since Sep. 2016. The lattice for user operation is a double mini-betay lattice [2], different from the lattice used for TPS commissioning [1]. Figure 1 shows the Twiss functions for the TPS double mini-betay lattice.

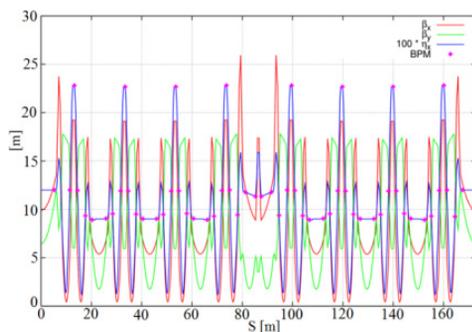


Figure 1: Twiss functions for the double mini-betay lattice in the TPS storage ring.

The TPS can operate in multi-bunch and single-bunch mode. The normal operating mode is the multi-bunch mode with lattice chromaticities of 0.7/0.8 (ξ_x/ξ_y). Recently, users requested operation in a hybrid mode by fall of 2019. Hence, a lattice with chromaticities of 0.8/2 (ξ_x/ξ_y) was developed than can provide higher single-bunch currents. The betatron tunes for these two lattices with chromaticities of 0.7/0.8 and 0.8/2 are the same at 26.14/14.24 (ν_x/ν_y).

The simulation codes MAD8 [3] and OPA [4] are used to optimize the linear and nonlinear lattice and Tracy-2 [5] is used to perform beam dynamics simulations. The injection efficiency is optimized up to 95%, and the beam lifetime is longer than 10 hours. Dynamic aperture (DA), frequency map analysis (FMA) [6-8], tune shift with energy,

[†] chiu.ms@nsrc.org.tw

tune shift with amplitude, and betatron coupling of the double mini-betay lattice with chromaticities of 0.8/2 are presented in the following sections. Linear lattice calibrations [9] for the double mini-betay lattice is performed every month with LOCO.

FREQUENCY MAP ANALYSIS (FMA)

Experimental Conditions

The storage ring lattice with chromaticities of 0.8/2 is filled with a train of 36 electron bunches, as shown in Fig. 2. The time duration of the bunch train is about 72 ns and the total beam current is about 10 mA. A pair of horizontal and vertical pinger magnets with a pulse width of about 3 μ s is installed between the 3rd and 4th injection kicker magnets in the storage ring. The revolution time of the electron beam is about 1.732 μ s. The bunch train is aligned to the peak of the output waveform of the pinger magnet such that the bunch train sees the kick from the pinger magnet only once and only at the first turn. This guarantees that the electron bunch trains see only a single-turn kick from the pinger magnet.

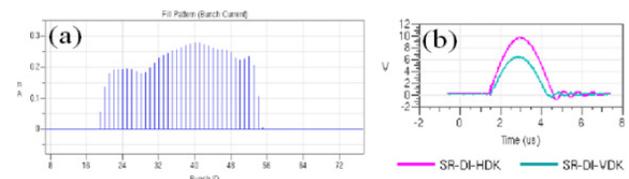


Figure 2: (a) Filling patterns for 36 electron bunches in the TPS storage ring. (b) Pinger output waveform.

Data Collection

A MATLAB script was developed to collect BPM data automatically. Two 'for loops' are used to increase kick strength of the horizontal and vertical pinger magnets until the beam is completely lost, independently kicking electron beam and exciting betatron oscillations. In order to get a regular frequency map, the increments for the pinger magnet kick strengths were chosen such that the square of pinger strengths are evenly spaced [8]. At each kick by the pinger magnets, the 172 BPMs, working in turn-by-turn (TbT) mode, store up to 7000 turns and were synchronized with the pinger magnets to record electron beam positions.

Data Processing

We chose first and second 510 turns (a multiple of 6, required by NAFF (Numerical Analysis of Fundamental Frequencies) [6]) of TbT data of the BPMs, located at the injection section, to calculate the betatron tunes of the first

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2019). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI

and second 510 turns by a MATLAB script ‘calcnaff’, provided by L. S. Nadolski. The inputs for ‘calcnaff’ are X and X’ for the calculation of horizontal tune, Y and Y’ for the calculation of vertical tune. X’ and Y’ are calculated by the following equation [10], where $\varphi_{21} = \varphi_2 - \varphi_1$ is the phase difference between BPM₂ and BPM₁, β_1 and β_2 are the beta functions at BPM₁ and BPM₂, respectively, and $\alpha_1 = -\beta'_1/2$ is taken at BPM₁.

$$x'_1 = x_2 \frac{csc\varphi_{21}}{\sqrt{\beta_1\beta_2}} - x_1 \frac{(cot\varphi_{21} + \alpha_1)}{\beta_1} \quad (1)$$

The lattice functions of the storage ring are calibrated by LOCO before collecting data. Before starting to calculate X’ and Y’, the DC term of X and Y (Here, the DC term means closed orbit distortion) must be subtracted.

Figure 3 shows the calibration curves for the nonlinear BPM response to kick strength due to nonlinear response of the capacitive pickups [11]. Hence, a calibration is required to correct the displacement such that DA and FMA can be derived correctly [12-13].

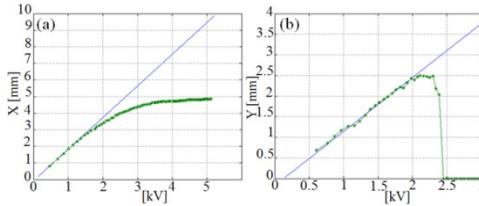


Figure 3: Calibration curves (blue) of BPM response versus kick strength of (a) horizontal and (b) vertical pinger.

Figure 4 shows the measured dynamic aperture (DA) and frequency map analysis (FMA) of the double mini-betay lattice with chromaticities of 0.8/2 at the injection section for a momentum deviation of $\delta=0\%$, while all insertion device gaps are open.

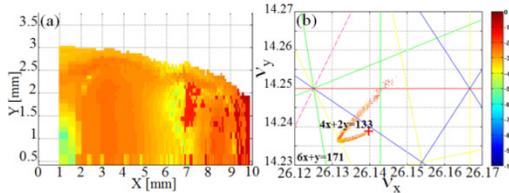


Figure 4: (a) Dynamic aperture and (b) frequency map for $\delta=0\%$, measured in the injection section.

Figure 5 shows the calculated dynamic aperture (DA) and frequency map analysis (FMA) of the double mini-betay lattice with chromaticities of 0.8/2, calculated in the middle of the injection section, considering a momentum deviation of $\delta=0\%$, and multipole errors only. The tune diffusion is calculated by the formula, $D = \log_{10}(\sqrt{\Delta v_x^2 + \Delta v_y^2})$, Δv is the tune difference between the first and second 510 turns.

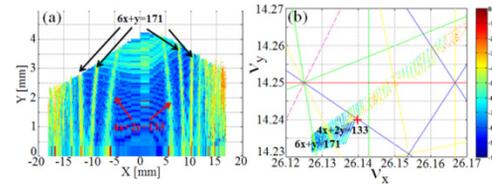


Figure 5: (a) Dynamic aperture and (b) frequency map for $\delta=0\%$, calculated for the middle of the injection section.

Figure 6 shows the calculated frequency map analysis (FMA) of the double mini-betay lattice with chromaticities of 0.8/2, calculated in the middle of the injection section by Tracy-2 [5], considering multipole errors only.

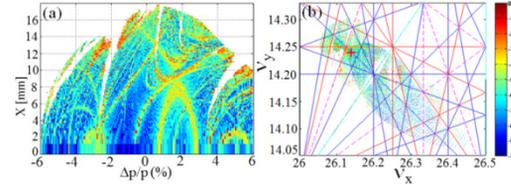


Figure 6: Frequency map analysis (FMA) as a function of momentum deviation, calculated in the middle of the injection section.

TUNE SHIFT WITH ENERGY

Figure 7 shows the tune shift with energy of the double mini-betay lattice with chromaticities of 0.8/2, (a) calculation, (b) measurement at a beam current of 10 mA. The relations between momentum deviation, RF frequency and momentum compaction factor can be expressed as the following equation.

$$\alpha \approx \alpha_1 + \alpha_2 \delta \approx -\frac{\Delta f/f}{\delta}, \quad \delta = -\frac{\alpha_1}{2\alpha_2} + \frac{\alpha_1}{2\alpha_2} \sqrt{1 - 4\frac{\alpha_2}{\alpha_1^2} \frac{\Delta f}{f}} \quad (2)$$

For the double mini-betay lattice with tunes of 26.14/14.24, $\alpha_1 = 2.3698 \times 10^{-4}$, $\alpha_2 = 2.1311 \times 10^{-3}$.

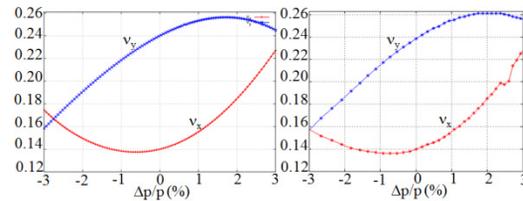


Figure 7: Tune shift as a function of the momentum deviation. (a) calculation, and (b) measurement.

TUNE SHIFT WITH AMPLITUDE

Figure 8 shows the tune shift with amplitude of the double mini-betay lattice with chromaticities of 0.8/2, (a) calculation, (b) measurement at a beam current of 10 mA.

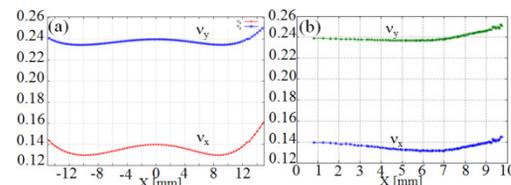


Figure 8: Tune shift with horizontal amplitude. (a) calculation, and (b) measurement.

This is a preprint — the final version is published with IOP

BETATRON COUPLING

Figure 9 shows the measured betatron normal mode tunes versus the current of the quadrupole QS1. Figure 10 and 11 show the spectrum of the normal modes, turn-by-turn BPMs, and beam image at the resonance point and away from resonance point, respectively.

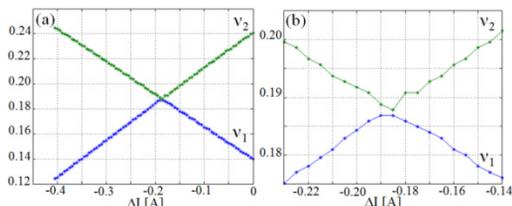


Figure 9: The measured betatron normal mode tunes versus the current of the quadrupole QS1.

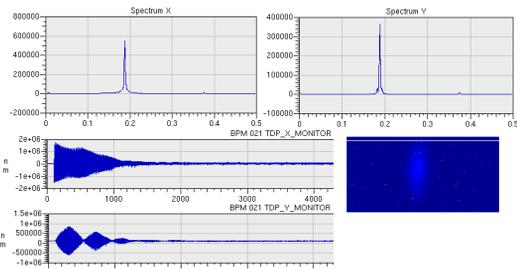


Figure 10: Spectrum of betatron oscillation, turn-by-turn BPMs, and beam image from bending magnet at the resonance point.

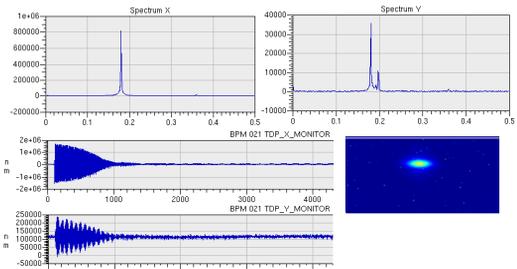


Figure 11: Spectrum of betatron oscillation, turn-by-turn BPMs, and beam image from bending magnet away from resonance point.

The normal mode (eigen-mode) tunes can be expanded in terms of uncoupled fractional tunes (ν_x, ν_y) and coupling strength by Eq. (3), where $\Delta = \nu_x - \nu_y$, $G_{1,-1,l}$ is the minimum separation between normal mode tunes. Here, $l = 12$. At the resonance point, $\nu_1 = 0.1869$, $\nu_2 = 0.1879$, $G_{1,-1,12} = 0.001$. The emittance coupling ratio is defined as $\kappa = \frac{G_{1,-1,12}^2}{G_{1,-1,12}^2 + 2\Delta^2} = 5 \times 10^{-5}$.

$$\nu_{1,2} = \frac{\nu_x + \nu_y}{2} \pm \frac{1}{2} \sqrt{\Delta^2 + G_{1,-1,l}^2} \quad (3)$$

SUMMARY

The TPS can be operated in multi-bunch and single-bunch mode. To provide a hybrid mode (multi-bunch mode plus an extra single-bunch), we developed a lattice

with chromaticities of $0.8/2$ (ξ_x/ξ_y) to reach higher single-bunch currents. The beam lifetime is longer 10 hours and injection efficiency is up to 95%. Beam dynamics simulations are evaluated, and lattice characterizations including dynamic aperture, frequency map analysis, tune shift with energy, tune shift with amplitude, and betatron coupling are reported. Test runs for the hybrid mode are in progress.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to L. S. Nadolski, who provided the NAFF package and FMA tools implemented by MATLAB.

REFERENCES

- [1] C.C. Kuo *et al.*, “Commissioning of the Taiwan Photon Source”, in *Proc. IPAC’15*, Richmond, VA, USA, May 2015, paper TUXC3, pp. 1314-1318.
- [2] M.S. Chiu *et al.*, “Double mini-betay lattice of TPS storage ring”, in *Proc. IPAC’11*, San Sebastián, Spain, May 2011, paper WEPC035, pp. 2082-2084.
- [3] H. Grote *et al.*, The MAD program (Methodical Accelerator Design), CERN/SL/90-13 (AP).
- [4] A. Streun, <https://ados.web.psi.ch/opa/>.
- [5] H. Nishimura, “TRACY, A Tool for Accelerator Design and Analysis”, in *Proc. 6th European Accelerator Conf.*, Rome, Italy, pp. 803-805.
- [6] J. Laskar, “Introduction to frequency map analysis”, in *Proc. of 3DHAM95 NATO Advanced Institute*, C. Simo Ed., S’Agaró, June 1995, pp. 134-150.
- [7] L. S. Nadolski and J. Laskar, “Review of single particle dynamics for third generation light sources through frequency map analysis”, *Phys. Rev. ST Accel. And Beams* 6 (11), 114801, 2003.
- [8] D. Robin, C. Steier, J. Laskar, and L. S. Nadolski, “Global dynamics of the Advanced Light Source revealed through experimental frequency map analysis”, *Phys. Rev. Let.*, vol. 85, 2000, pp. 558-561.
- [9] F.H. Tseng, C.H. Chen, and P.J. Chou, “Optics correction for routine operation at the Taiwan Photon Source”, presented at *IPAC’19*, Melbourne, Australia, May 2019, paper MOPGW093, this conference.
- [10] S.Y. Lee, *Accelerator Physics*, the 4th Ed. (World Scientific, 2019), p. 100.
- [11] E.S. Bozoki, “Determination of beam position from induced electric signals”, *Nucl. Instrum. Methods Phys. Res. A*, vol. 307, 1991, pp. 195-206.
- [12] M. Pont, N. Ayala, G. Benedetti, M. Carla, Z. Marti, and R. Nuñez, “A pinger magnet system for the ALBA synchrotron light source”, in *Proc. IPAC’15*, Richmond, VA, USA, May 2015, paper WEPMN050, pp. 3039-3042.
- [13] C.H. Chen *et al.*, “Frequency map analyses of the transverse beam dynamics at the TPS”, presented at *IPAC’19*, Melbourne, Australia, May 2019, paper WEPTS053, this conference.