DESIGN STUDY OF LOW EMITTANCE LATTICE FOR TAIWAN LIGHT SOURCE AT 1GEV

C.Y. Lee#, National Tsing Hua University, Hsinchu, Taiwan.
P.J.Chou, C.C. Chiang, NSRRC, Hsinchu, Taiwan, and S.Y. Lee, Indiana University, USA.

Abstract

We explored the possibility for the existing 1.5 GeV TLS storage ring to be operated at 1 GeV as a high brightness VUV light source after the completion of 3 GeV Taiwan Photon Source (TPS). To increase the spectral brightness, we need to reduce the beam emittance as much as possible without altering the existing hardware configuration. The theoretical minimum emittance (TME) that could be achieved at 1GeV for non-achromatic lattice is 3.8 nm-rad. However, this could not be achieved without introducing harmonic sextupoles to enlarge the dynamic aperture. Preliminary results of low-emittance lattice without harmonic sextupoles will be presented.

INTRODUCCTION

The TLS storage ring was designed as a three-bend achromat (TBA) lattice with a six fold symmetry. Accelerator parameters of TLS storage ring at 1 GeV are shown in Table 1. The lattice function of TLS storage ring (TBA lattice) for one period is shown at Fig.1.

Table 1: Parameters of TLS Storage Ring (TBA Lattice) at 1 GeV

Circumference	120 m
Nominal energy	1.0 GeV
Revolution period	400 ns
Damping partition	1.28/1.00/1.71
Damping time [ms]	2.46/3.16/1.84
RF frequency	499.654 MHz
Harmonic number	200
Natural emittance	11.5 nm-rad
Relative Energy Spread	4.95E-04
Momentum compaction	6.49E-03
Energy loss per turn	25.3 KeV
Betatron tune (H/V)	7.13/4.18
Synchrotron tune	1.285E-2
Natural chromaticity (H/V)	-15.88/-7.21

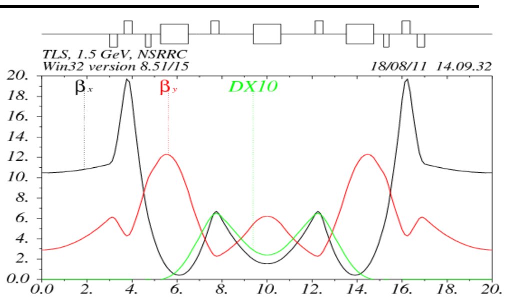


Figure 1: Lattice function of TLS storage ring for one period (TBA lattice).

To lower the emittance, we allowed a small nonzero dispersion function in the straight sections and followed the minimization procedures [1] to attain the TME lattice. We found that the TME was attainable but the dynamic aperture was too small. Besides the phase space tracking showed a strong 3rd order resonance. Using a less ambitious goal for beam emittance, we found a lattice design with a beam emittance 6.1 nm-rad (a factor of two smaller) and good dynamic aperture. No harmonic sextupole was used in the low-emittance lattice that we had designed.

LINEAR LATTICE DESIGN

MAD program [2] was used to adjust the quadrupole settings for a smaller emittance and proper working tune such that harmful nonlinear resonance was avoided. A non-achromatic three-bend lattice was found with good dynamic aperture. Accelerator parameters of TLS storage ring at low-emittance mode are shown in Table 2. The lattice function for one period is shown in Fig.2.

Table 2: Parameters of TLS Storage Ring at 1GeV, Operating at Non-Achromatic Low-Emittance Mode

Circumference	120 m
Nominal energy	1.0 GeV
Revolution period	400ns
Damping partition	1.22/1.00/1.78
Damping time [ms]	2.59/3.16/3.33
RF frequency	499.654 MHz
Harmonic number	200
Natural emittance	6.1 nm-rad
Energy Spread	4.86E-04
Momentum compaction	5.01E-03
Energy loss per turn	25.3 KeV
Betatron tune (H/V)	7.46/4.398
Synchrotron tune	1.129E-2
Natural chromaticity (H/V)	-17.32/-9.53

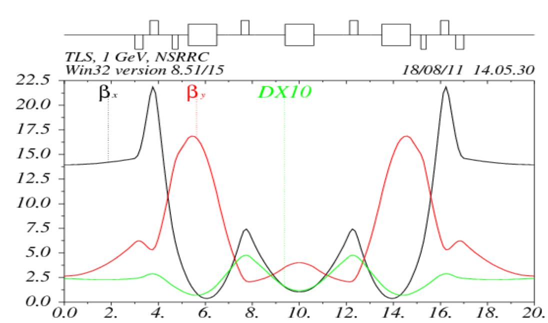


Figure 2: Lattice function of TLS storage ring for one period (non-achromatic low-emittance mode).

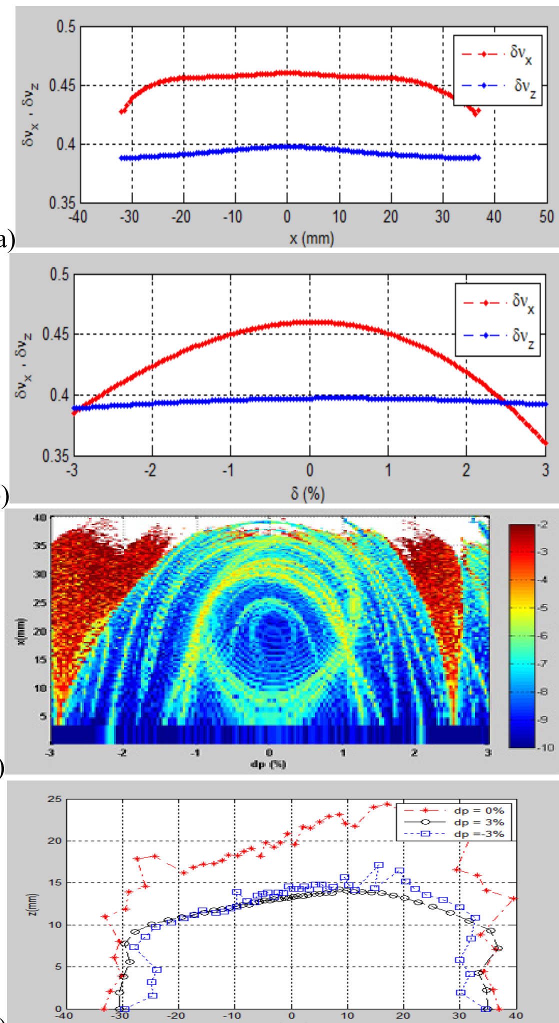
As depicted in Fig.2, the low-emittance mode lattice is non-achromatic. The maxima of both β_x, β_y are larger than

#tac0626@hotmail.com

the present TBA lattice in operation, which results in a larger value for natural chromaticity as shown in Tables 1 and 2. Therefore, stronger sextupole strengths are required in the low-emittance mode to correct the natural chromaticity.

NONLINEAR DYNAMICS

TRACY-II [3] was used for the tracking studies of nonlinear beam dynamics and Touschek lifetime. Both the horizontal and vertical chromaticity were corrected to small positive values. Tracking results of bare lattice without multipole error are shown in Fig.3.



(a)
(b)
(c)
(d)

Figure 3: (a) tune shift vs. amplitude (b) tune shift vs. momentum (c) frequency map analysis (x v.s. dp/p) (d) dynamic aperture. The tracking simulations were done with chromaticity ξ_x/ξ_y = *0.095/0.065*

Results of tracking simulations including multipole errors [4] are shown in Fig. 4. As shown in Fig. 4, the dynamic aperture was reduced when multipole errors were included.

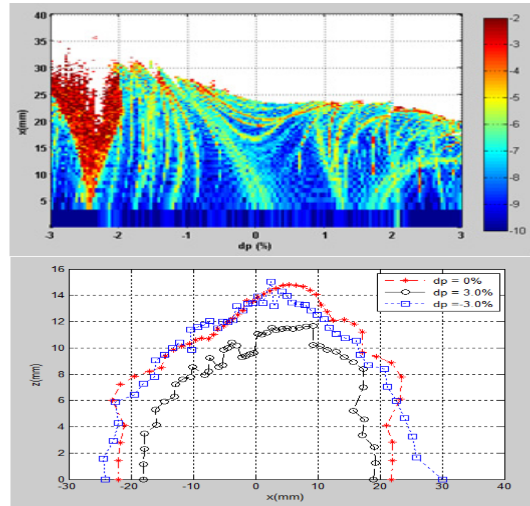


Figure 4: Top: frequency map analysis (x v.s. dp/p), bottom: dynamic aperture ξ_x/ξ_y = *0.095/0.065*. Multipole errors were included in the tracking simulations

TOUSCHEK LIFETIME

The Touschek life time was calculated with TRACY-II including 1% emittance coupling and multipole errors. Parameters used for the lifetime calculation are shown in Table 3.

Table 3: Parameters for Touschek Lifetime Calculation

Gamma factor	1956.947
RF frequency	499.654 MHz
Synchrotron tune	1.129E-2
Synchrotron phase	3.125 rad
Natural emittance	6.12 nm-rad
Energy Spread	4.95E-04
Beam size	0.31mm/0.013mm
Bunch length	2.911mm
Bunch current	1.43mA

The momentum acceptance along the ring is shown in Fig.5. The calculated Touschek lifetime is 1.54 hours for low-emittance mode at 1 GeV. The main reasons of shorter lifetime are lower beam energy and smaller beam size according to the formula of Touschek lifetime .

$$\tau_T \approx \frac{48\pi\gamma^2\sigma_s\sigma_x\sigma_y}{r_e^2 Nc}(\Delta p/p)^3$$

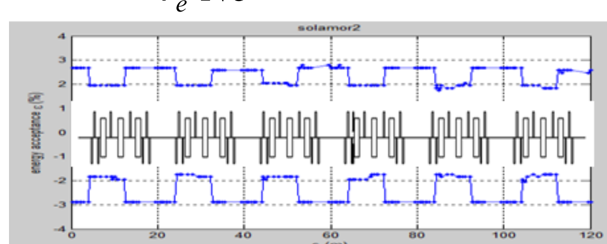
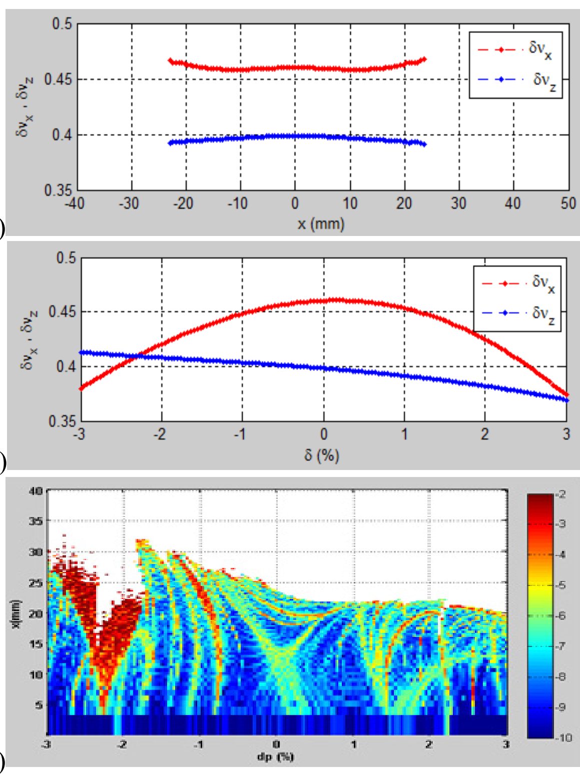


Figure 5: Energy acceptance along the ring with 1% coupling and multipole error.

LOW-EMITTANCE LATTICE AT 1.5 GEV

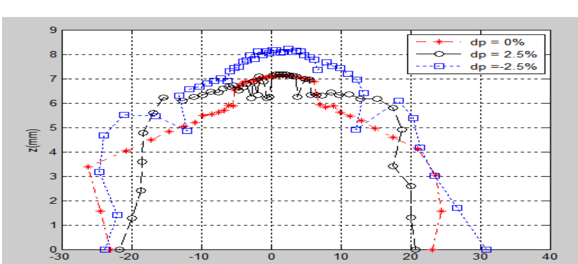
We plan to test the low-emittance mode lattice on TLS storage ring at 1.5 GeV and gain experience for the commissioning of TPS in 2014. The emittance of TLS at 1.5 GeV in the low-emittance mode is 13.2 nm-rad. Due to technical problem, the gap of wiggler W200 can not be opened. Therefore, we have to include wiggler W200 in the lattice configuration for our planned beam test in the near future.

The wiggler W200 was modelled in MAD by using H. Wiedemann's method [5]. The vertical tune shift due to wiggler W200 was corrected so that the unwanted nonlinear resonance could be avoided. Results of nonlinear beam dynamics tracking after the tune correction are shown in Figs.6 and 7. The calculated Touschek lifetime at 1.5 GeV including wiggler W200 is 16.96 hrs. Parameters used for Touschek lifetime calculation are shown in Table 4.



(a) (b) (c)

Figure 6: (a) tune shift vs. amplitude (b) tune shift vs. momentum (c) frequency map analysis (x v.s. dp/p), wiggler W200 was included.



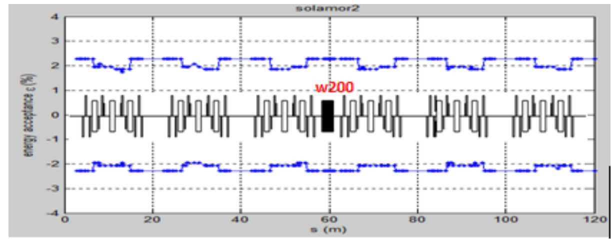


Figure 7: Top: dynamic aperture, bottom: momentum acceptance along the ring with 1% coupling. Wiggler W200 was included.

Table 4: Parameters used for Touschek lifetime calculation at 1.5 GeV (low-emittance mode).

Gamma factor	2935.420
RF voltage	1.6 MeV
RF frequency	499.654 MHz
Synchrotron tune	1.303E-2
Synchrotron phase	3.125 rad
Natural emittance	13.184 nm-rad
Energy Spread	7.27E-04
Beam size	0.36 mm/0.021 mm
Bunch length	5.349 mm
Bunch current	1.43 mA

The increase of Touschek lifetime from 1.5 hours at 1 GeV to 16.96 hours at 1.5 GeV is mainly due to the increase of beam energy , emittance and beam size.

SUMMARY

Without altering the hardware configuration of current TLS storage ring, we have designed a lattice with lower emittance 6.12 nm-rad and good dynamic aperture at 1 GeV. However, the Touschek lifetime is less than 2 hrs. Bunch lengthening with harmonic cavity should be considered if we plan to operate TLS at 1 GeV low-emittance mode in the future. If we want to achieve the TME lattice, harmonic sextupoles and hardware modification will be needed in order to attain a good dynamic aperture.

ACKNOWLEDGEMENT

The authors would like to thank M.S. Chiu, H.J. Tsai and H.P. Chang at NSRRC for their friendly discussion and open assistance regarding the TRACY-II and model of ID W200.

REFERENCES

[1] S.Y.Lee, Chapter 4.III ,"Accelerator Physics", 2nd edition, World Scientific, 2004.
[2] H. Grote, *et al.*, The MAD program (Methodical Accelerator Design), CERN/SL/90-13 (AP).
[3] TRACY-II, SOLEIL's version.
[4] SRRC-MM-IM-92-02, NSRRC internal report,
[5] Sec.3.2.6,"Effecs in the presence of insertion device", TPS Design Handbook (Oct., 2009), NSRRC.