NONLINEAR BEAM DYNAMICS OF TPS

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Abstract

A design study of 3.0 GeV high performance low emittance storage ring, Taiwan Photon Source, has been conducted recently. The natural emittance of the storage ring can be as low as 1.7 nm-rad in our design and its lattice is a 24-cell double bend achromat type with circumference of 518.4 m, which will be located in the existing NSRRC site in Hsinchu. The strong focusing requires strong aberration correction with nonlinear sextupole magnets. The distribution of the sextupoles and number of families are studied to ensure a good dynamic aperture. The nonlinear effects in both betatron and synchrotron motions are investigated. The physical aperture limitations are included in the study, and the Touschek lifetime is calculated. The tracking data are analyzed using frequency map analysis method and corresponding beam dynamics behaviour can be revealed more precisely.

INTRODUCTION

Many lattice design options for the 3.0 GeV TPS project have been studying. One of the lattice options with the circumference 518.4 m, designated 24P18K1, had been proposed last year [1]. Based on this design, detailed studies were carried out. Small chambers for insertion devices (IDs), with vertical chamber size ±5 mm (see the Fig. 1), are added in the particle tracking of TRACY-2 [2].

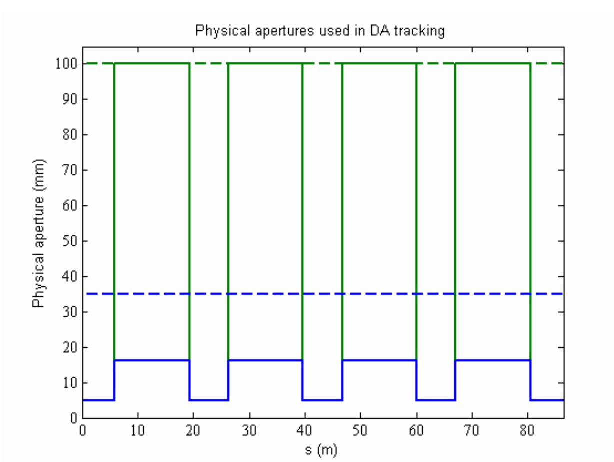

Figure 1: The half-widths of designed normal chambers are 35 mm in X and 16 mm in Y. The vertical half-width of the small ID chambers is 5 mm.

The frequency map analysis (FMA) result (see Fig. 2) shows that the survival region of the dynamic aperture (DA) is eaten away by some resonance lines. And its vertical region is also reduced by the physical limitation (see the upper plot in Fig. 2b). It should be noted that, except the ID chambers, the upper case in Fig. 2 uses the default physical aperture limitation ±100 mm of the TRACY-2.6 code in the DA tracking. For the lower case in Fig. 2, not only the ID chambers but also the designed normal chamber sizes, ±35 mm in X and ±16 mm in Y, are used. Due to the horizontal physical aperture 35 mm at the maximum beta location, the survival region at the long straight centre (see the lower plot in Fig. 2b) in X is shrunk to be about 19 mm. It also includes the non-linear effect of beta function change due to the large amplitude.

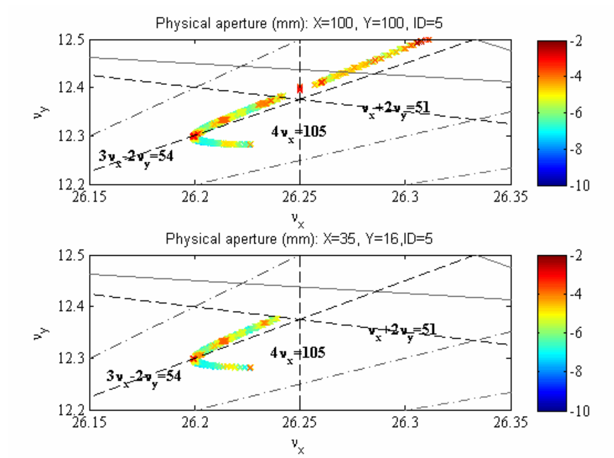

Figure 2a: The frequency map shows that tracking particle has larger frequency diffusion when it hits resonance lines, 3Qx-2Qy=54, Qx+2Qy=51 and 4Qx=105. It causes the dynamic aperture dipped.

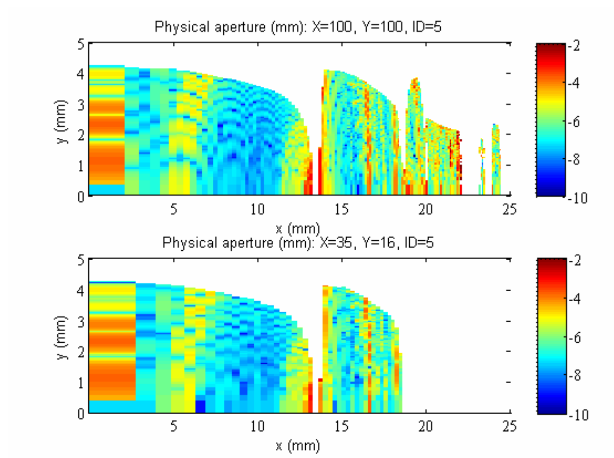

Figure 2b: The dynamic aperture at the long straight centre with the small chambers for IDs is dipped and shrunk.

Such an effect will cause the difficult in injection and reduce the beam lifetime. We need to eliminate or avoid

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these resonance lines to enlarge dynamic aperture as possible. The process and results are presented in the following.

IMPROVEMENT

For reducing the effects of resonance lines, one may change the working tunes and reduce the resonance strengths [3]. The change of working tunes needs further adjustment in chromaticity correction. It includes the linear and non-linear fine-tuning. Followings are our procedure.

Shift Working Tunes to (26.31, 12.21)

We properly shift the working tunes from (26.22, 12.28) to (26.31, 12.21) to be away from the resonance lines. The injection requirement is also taken into account. We find it's better to use two quadrupole families beside long straight sections to adjust the working tunes. Thus the linear optics is (see Fig. 3) less perturbed. Inevitably, the chromaticity correction also needs to be re-adjusted. The sextupole set is then optimised for the non-linear beam dynamic behavior. The whole procedure can be separated into two parts:

- Using TRACY-2, we fit the desired working tunes and then corrected the chromaticity.
- Repeatedly, we optimise the sextupoles by using BETA code in order to enlarge the dynamic aperture and then did the FMA by using TRACY-2.

After some iterative searching in shifting the working tunes and refining the sextupole set, optimal results can be obtained.

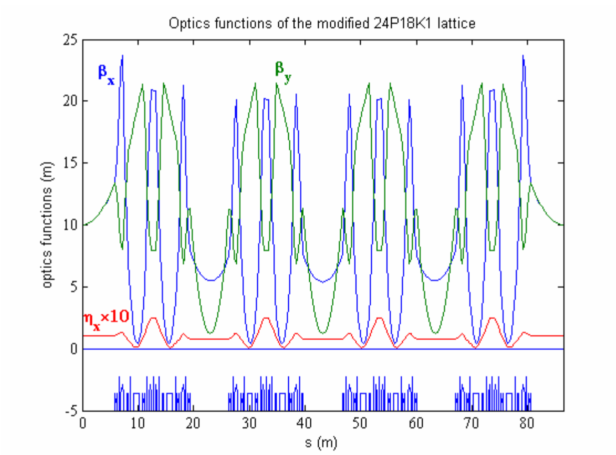

Figure 3: The optics of the lattice after refinement.

Achievements

The problem of the dynamic aperture with the ID chambers is removed finally. The survival regions observed at the long straight centre with different physical aperture limitations are shown in Fig. 4a. FMA presents the path of tune shift in Fig. 4b. The lattice after refinement is less sensitive to the 4Qx=105 resonance line.

The amplitude dependent tune shifts are shown in Figure 5. In general plan, we try to let these curves as flat as possible. In vertical, we have made it flat enough, but it's hard to flatten the horizontal part without changing the distribution/locations of sextupoles. The lattice refinement, including the shift of working tunes and the optimisation of sextupole strengths, also separates the horizontal and vertical tunes (see Fig. 6) to avoid the coupling resonance due to the momentum deviations. Fig. 7 shows the energy dependent dynamic aperture with physical aperture limitation.

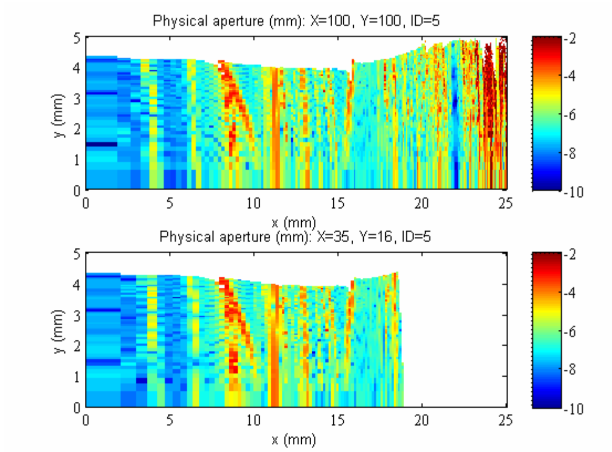

Figure 4a: The survival regions at the long straight centre are with different physical limitations, small ID chambers and normal chambers, after lattice refinement.

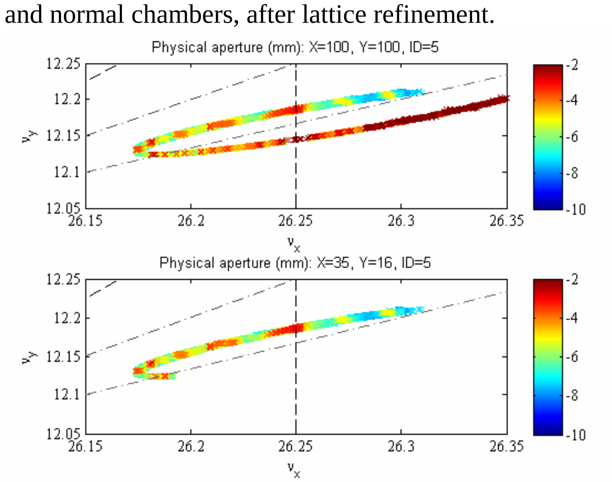

Figure 4b: The frequency map of the modified lattice shows the path of amplitude dependent tune-shift in dynamic aperture tracking.

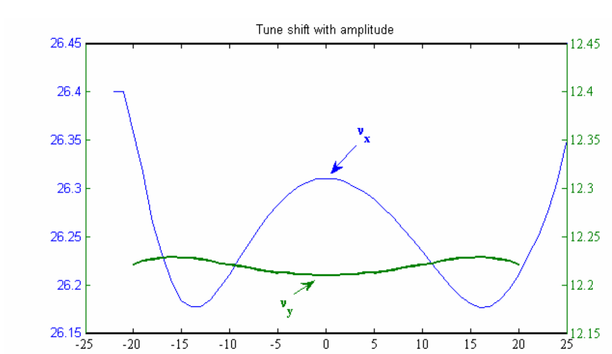

Figure 5: Amplitude dependent tune shifts of the modified lattice.

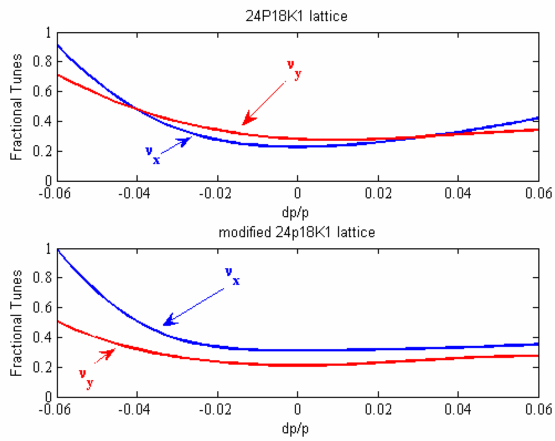

Figure 6: Tune shifts with energy of the original (upper) and modified (lower) 24p18k1 lattices. The crosses of horizontal and vertical tunes have been removed.

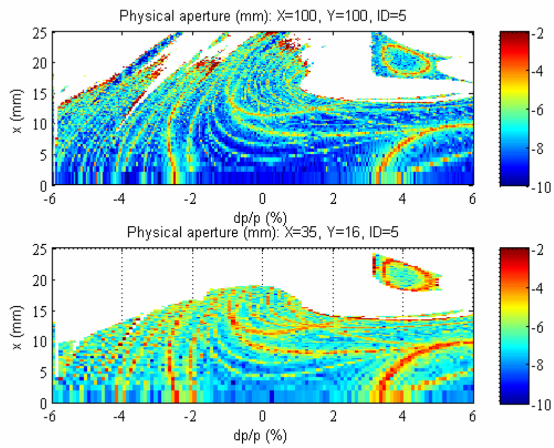

Figure 7: Horizontal survived regions of TRACY-2's off-energy particle tracking. Except the ID's chambers, the upper one is with the default physical limitation of TRACY-2.6 and the lower is with designed chambers.

Touschek Lifetime

Using BETA code, we carried out the Touschek lifetime calculations before and after the lattice refinement. Fig. 8 shows there is an increase of Toushek lifetime about 5 hours after refinement of lattice's linear and non-linear configuration. The decrease of Touschek lifetime below 2 MV RF gap voltages is due to the competition of bunch length, energy acceptance, and dynamic aperture.

DISCUSSION

Because the strong focusing is required for the low emittance lattice design, the induced large negative natural chromaticities must be corrected by using strong chromatic sextupoles. Such strong sextupoles often increase serious non-linear beam dynamic effects and which must be reduced and minimized by adding some harmonic sextupole families. The dynamic aperture or the survival region of particle tracking is required to be large enough for efficient injection and reasonable beam lifetime.

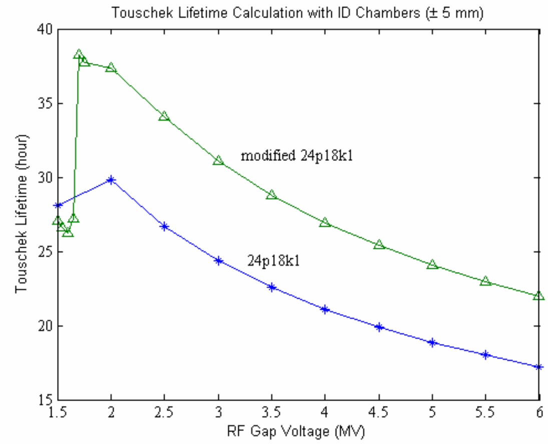

Figure 8: Touschek lifetime vs. different RF gap voltages of the modified lattice is compared with the original lattice.

Some considerations in our non-linear beam dynamics optimisation are:

- Required sextupole strengths should be reduced as weak as possible.
- Tune shifts with amplitude and momentum should be as flat as possible.
- It's an iterative searching process between linear optics and non-linear properties in the optimisation of a lattice design.
- Once an acceptable working lattice is obtained, one may optimise the dynamic aperture with small chambers.

We have improved the survival region of particle tracking for our 24P18K1 lattice by shifting the working tunes to avoid the resonance lines and slightly adjustment of sextupoles. The crossover in the tune-shift with energy is also avoided.

REFERENCES

[1] C. C. Kuo, et al., "Lattice Study for Taiwan Photon Source", PAC'05 Proceedings, p. 2989.

[2] J. Bengtsson and L. Nadolsky, TRACY-2.6 BNL version. H.P. Chang and H.J. Tsai, TRACY-2.6 NSRRC version, which is modified from the BNL version.

[3] M. Belgroune, et al., "Application of the Frequency Map Analysis to the New Lattice of the SOLEIL Project", EPAC 2002 Proceedings, p. 1229.

[4] B. Brunelle, et al., "Non-linear Beam Dynamics and Beam Lifetime on the SOLEIL Storage Ring", EPAC 2004 Proceedings, p. 2035.