DESIGN AND OPTIMISATION OF SPS-II STORAGE RING

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Abstract

Siam Photon Source (SPS) in Thailand has been operating and providing synchrotron radiation to users for more than a decade, leading to growing user community in South East Asia region. This gives rise to the possibility of constructing a new 3 GeV light source which could provide synchrotron light with higher photon energy and higher brilliance than the existing 1.2 GeV machine. Hybrid multi-bend achromat (HMBA) lattice design providing small natural beam emittance is a promising choice. In this paper, the Double-Triple Bend Achromat (DTBA) design with extra straight section scaled from Diamond Light Source upgrade lattice [1] is presented. Lattice optimisation with simplified magnet specifications still allows natural emittance of about 900 pm·rad for a 321.3 m circumference ring with sufficient dynamic aperture.

INTRODUCTION

SPS storage ring has been operating with 1.2 GeV beam energy and ~41 nm·rad beam emittance. The next step for the future to respond to the growing user community is to provide better photon beam characteristics and stay globally competitive.

As the ultralow emittance frontier become more accessible with MBA lattice leading by MAX-IV [2], the new machine will have much smaller electron beam emittance, delivering higher photon flux with high degree of transverse coherence. In the framework of lattice design of the new storage ring for SPS-II, we are considering Double Triple Bend Achromat (DTBA) lattice. The DTBA lattice has been developed as a candidate for Diamond Light Source storage ring upgrade project (Diamond-II). The combination of Double-Double Bend Achromat (DDBA) [3] and HMBA of ESRF-II [4] cells, DTBA allows low emittance and more space for IDs.

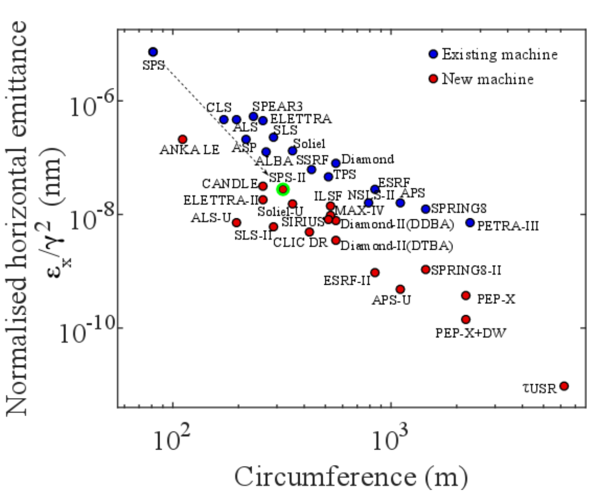

Figure 1: Normalized horizontal beam emittance of existing and planned storage rings.

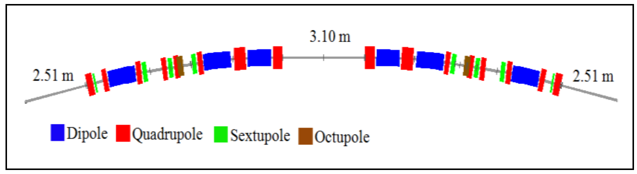

Figure 2: DTBA cell layout.

Figure 1 shows normalised horizontal emittance against the ring circumference of the existing (blue dots) and new (red dots) machines. Substantial reduction of horizontal emittance can be achieved with MBA design compared to existing machines employing DBA or TBA cell. Larger rings could use more dipoles and reduce the beam emittance further. The new SPS-II will perform significantly better and stay globally competitive. Note that the comparison in Figure 1 does not consider the space available for IDs which is one of the benefits of DDBA and DTBA cells.

LATTICE DESIGN

The main objective of the new lattice design is to achieve very low electron beam emittance while maximizing utilization potential of the machine, with feasible/existing technologies. One of the most promising lattice solutions is the DTBA cell as shown in Figure 2. Not only does it have very small beam emittance, but also doubles the number of available straights for insertion devices. The new machine will offer both excellent photon beam quality and better productivity. Elegant [5] is the main code in this study.

Linear Optics

The DTBA cell was simplified for SPS-II to minimize the cost and complexity. There are 6 dipoles in total in

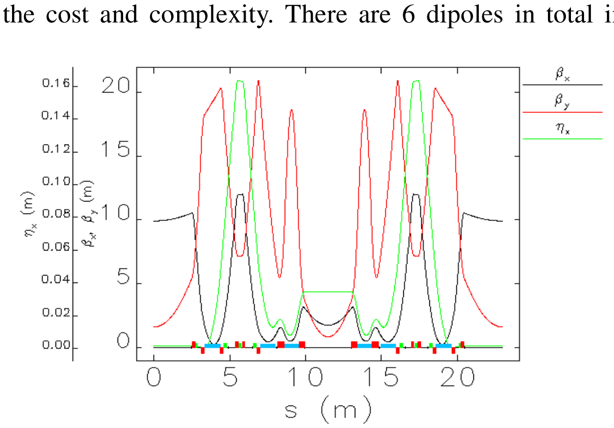

Figure 3: Twiss functions for one DTBA cell in SPS-II.

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each cell, two of them have transverse gradient and another two have longitudinal gradient. The longitudinal gradient dipole in the original cell was changed to normal dipole. In non-dispersive straight condition, the strong normal field of the gradient (combined function) dipole close to the middle of the cell and weaker field in the edge dipole help reducing the beam emittance. However, strong normal field in the gradient dipole may limit the maximum achievable field gradient due to field saturation in iron pole. The normal field was limited to 0.6 T and the maximum transverse gradient was reduced to ~27 T/m. The maximum quadrupole strength is below 60 T/m which is moderate compared to other machines. Figure 3 shows the Twiss parameters in one DTBA cell. There are two types of straight sections: standard straight (5.03 m) and middle straight (3.10 m). In both type of straights, Twiss functions were matched to achieve small vertical beta and dispersion functions. The dispersion function in the middle straight is non-zero thus small dispersion function was obtained in the adjacent dipole which is required to minimise the beam emittance. The full ring will be composed of 14 DTBA cells giving the total circumference of 321.3 m. It is also required that the fractional tune has to be below half integer to avoid resistive wall instability. Table 1 describes the main parameters of the existing SPS and the new SPS-II.

Table 1: Machine Parameters

Parameters	**SPS**	**SPS-II**
Circumference (m)	81.3	321.3
Energy (GeV)	1.2	3.0
Emittance (nm·rad)	41.0	0.96
Tune Q_x, Q_y	4.75, 2.82	34.24, 12.31
Straight/circumference	0.33	0.35

Nonlinear Optics

In order to minimise the effect of nonlinear component generated by chromatic sextupoles in the dispersion bumps, phase advance difference between the sextupoles was matched to an odd number of pi (3π and π in horizontal and vertical planes respectively). This technique was initially used in ESRF-II lattice design which eases the lattice optimisation. This concept also applies to DTBA cell. The chromaticity was corrected to small positive number (2, 2) as we will operate above transition condition.

Two free variables: sextupole and octupole strengths are used in parameter scan. Then tune scan in Figure 4 was performed to find an optimum solution with sufficient dynamic aperture and lifetime. In all scans the chromaticity was fixed to 2 in both planes. The lifetime was calculated using 300 mA current in 500 bunches, vertical emittance of 8 pm·rad and zero current bunch length. The lifetime will be better in the actual machine because of longer bunch length due to the effect of IDs and beam current etc. Slightly lower beam emittance can be found with larger horizontal tune but the lifetime drops

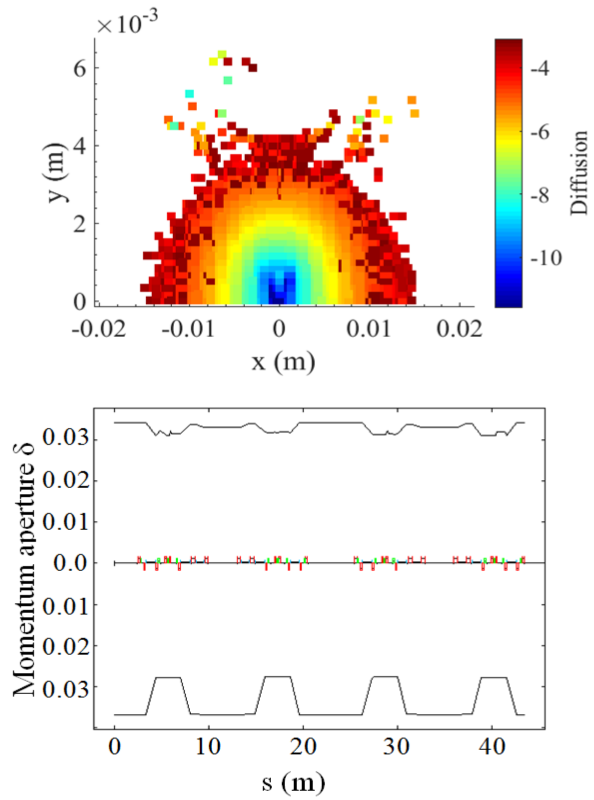

Figure 5: Dynamic aperture (above) and momentum aperture (below) for 2 cells of the SPS-II baseline lattice.

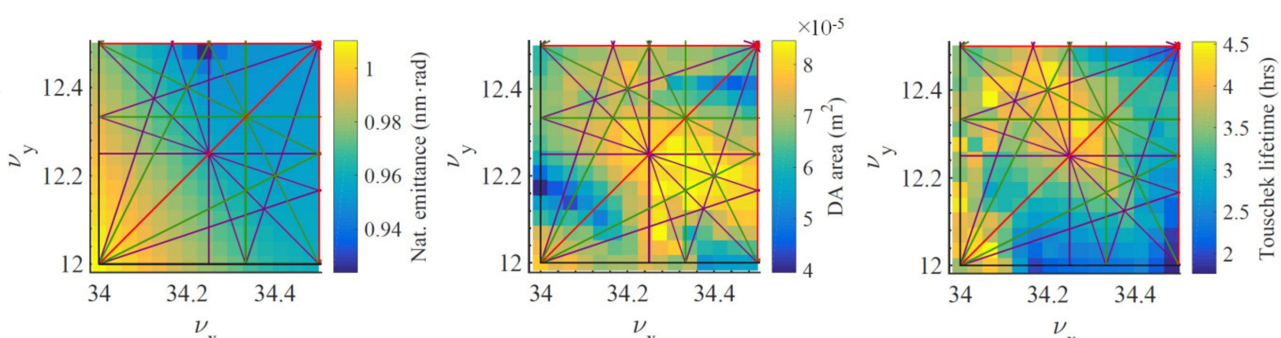

Figure 4: Tune scan results showing natural emittance, dynamic aperture area and Touschek lifetime. Resonance lines: 1st (black), 2nd (red), 3rd (green), 4th (purple).

around half integer line. The tune point was selected at (34.24, 12.31) considering both good dynamic aperture and lifetime. In the tune space, there is some room for the working point to be varied without worsening the machine performance.

Figure 5 shows the dynamic aperture and momentum aperture for the ideal machine calculated by particle tracking for 1024 turns including RF cavity and radiation effect. Diffusion represents the particle stability given by:

$$d = \log(\Delta Q_x^2 + \Delta Q_y^2) \quad (1)$$

where ΔQ_x and ΔQ_y are tune differences between two halves of the total tracking N turns in horizontal and vertical plane respectively. The dynamic aperture is larger than 14 mm which is sufficient for off-axis injection without injection cell. Momentum aperture larger than 3 % can be achieved, and the Touschek lifetime is more than 4 hours.

Effect of ID in Middle Straight

DTBA cell provides two types of straight: 5.02 m long standard and 3.10 m long middle straights. The standard straight is non-dispersive and strong IDs can be installed without deteriorating the beam parameters. Dispersive straight section in the middle of the cell can be used to accommodate an ID as well. However, too strong field ID could introduce emittance and energy spread growth. It is required that the effects of the ID field strength in the middle straight on the emittance and energy spread growth have to be acceptable. In the 3.10 m long middle straight, it is possible to accommodate a 2 m long undulator. An undulator with λ = 21 mm was used in this study. The emittance and energy spread growth as functions of undulator field is shown in Figure 6. It is clear that there is no emittance growth if the undulator field is below 1.5 T while the energy spread will not increase if the field is below 1.02 T. The effect of the undulator on the beam parameters can be minimize by reducing the dispersion function in the middle straight; however, the dispersion function in the adjacent dipole may not be optimized leading to larger beam emittance.

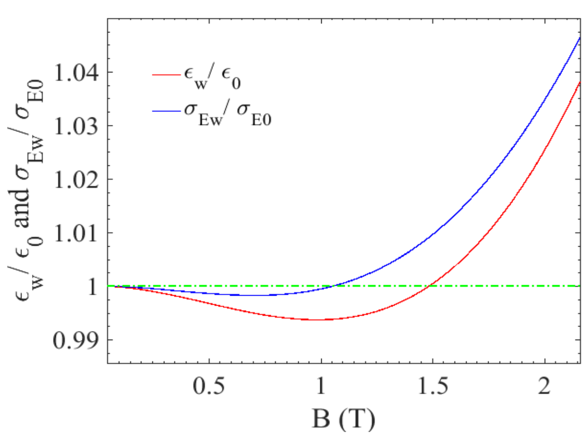

Figure 6: Variation of emittance (red) and energy spread (blue) with undulator field strength.

MAGNET SPECIFICATIONS

In the lattice design process, the engineering feasibility of magnet fabrication was taken into account. The only special magnet is the combined function dipole (with transverse gradient). The dipole field and gradient in the combined function dipole have to be optimised with care to avoid saturation in the pole and complexity of the pole shape. The strength limit of the magnets was checked and readjusted to obtain a good lattice solution with reasonable magnet specifications as described in Table 2.

Table 2: Magnet Specifications

Magnet	Field, Gradient
Dipole	0.87 T
Combined fn. dipole	0.6 T, 27 T/m
Quadrupole	60 T/m
Sextupole	2020 T/m^2
Octupole	71000 T/m^3
Corrector	0.8 mrad

CONCLUSION

The presented design promises workable solution for SPS-II with reasonable parameters considering moderate requirement on the magnets. However, there are some room for improvement on the lattice design. Effects of chromaticity have to be investigated. More sophisticated optimisation algorithm like Multi-Objective Genetic Algorithm (MOGA) could provide a better solution. Error analysis will be needed to ensure the robustness of the solution in the next step. DTBA concept is a promising choice for new facility seeking both beam quality and productivity.

ACKNOWLEDGMENT

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