A HYBRID MULTI-BEND ACHROMAT LATTICE DESIGN FOR SSRL-X*

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Abstract

We present a lattice design for SSRL-X which is a green-field low-emittance storage ring proposal. The lattice is based on the hybrid multi-bend achromat and has natural emittance of 63 pm with 24-cells and 570 m circumference under 3.5 GeV energy. Insertion of damping wigglers on dedicated straight sections futher reduces natural emittance to 34 pm, which yields 18 pm under the full-coupling condition. Performance of the lattice and preliminary optimization study is given.

INTRODUCTION

We are exploring options to provide more bright and reliable synchrotron light source which can serve Stanford Synchrotron Radiation Lightsource (SSRL) for next decades. It includes upgrade of existing SPEAR3 storage ring into a multi-bend achromat lattice, a ring fits the 2.2-km PEP tunnel and a 570-m green-field storage ring.

SSRL-X is a green-field low-emittance storage ring proposal with 3.5 GeV energy and 63 pm natural emittance. Design of the storage ring is based on the hybrid multi-bend achromat which is widely adopted for 4th generation storage rings. Emittance of the storage ring is further reduced to 32 pm with additional damping from damping wigglers. The ring can achieve minimum emittance with the full-coupling condition which divides emittance as much as $\varepsilon_x \frac{J_x}{J_x+1}$ on both transverse planes. The value is 18 pm and it is close to diffraction-limit of 10-KeV photon beam, 10 pm.

In this paper, we present characteristics and matching constraints of SSRL-X, and show nonlinear performance. Preliminary optimization based on 2D scanning is given. Performance limit due to intrabeam scattering (IBS) is also investigated.

SSRL-X OPTICS

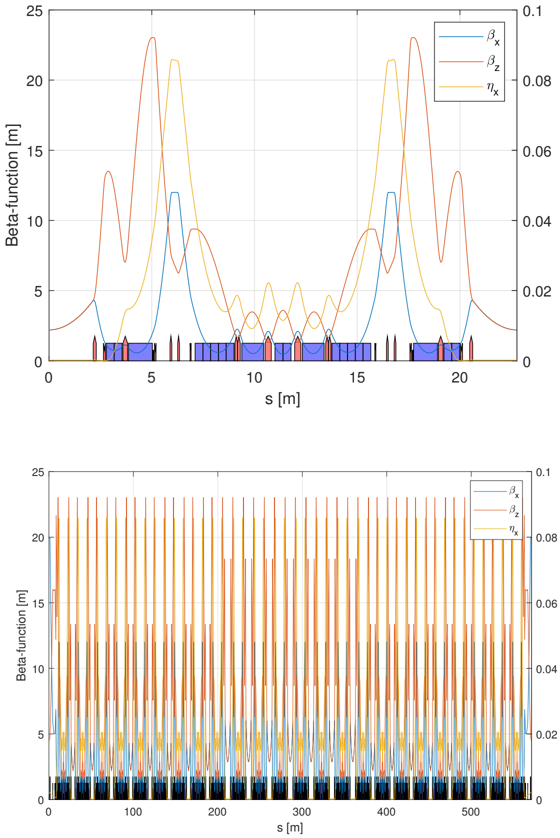

Figure 1: Twiss functions of a unit cell (upper plot) and a ring (lower plot).

Twiss-functions of one standard cell and SSRL-X ring are shown in Fig. 1. It is a hybrid multi-bend achromat which has strong FODO region at the middle and two large dispersion bumps where chromatic sextupole magnets are located. Phase advances between adjacent dispersion bumps are satisfying $\psi_x = 3\pi$ and $\psi_y = 3\pi$ for local cancellation of resonance driving terms caused by chromatic sextupole magnets. Bending magnet region near the dispersion bumps consists of longitudinal gradient bending magnets to suppress emittance increase in the large dispersion region. A quadrupole is added inside the outer longitudinal gradient bending magnet region to match horizontal and vertical beta-functions to $L/2$ where L is length of straight section.

A ring consists of 17 standard cells, 5 long-straight cells, and 1 injection cell (Fig. 1 lower plot). Long-straight cells and an injection cell are modifications of the standard cell. Long-straight sections are dedicated for damping wigglers. Additional damping from wigglers reduces the natural emittance from 63 pm to 34 pm. The injection cell provides large horizontal beta-function region which makes off-axis injection feasible. Although these cells have different lengths compared to the standard cell, 24-cell periodicity is preserved in terms of phase advance. They have same phase advance with the standard cell and satisfy $\psi_x = 3\pi$ and $\psi_y = 3\pi$ between the adjacent dispersion bumps. The ring also has one octupole family and one decapole family in each cell to effectively cancel detuning coefficients. Lattice parameters are listed in Table 1.

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* Work supported by U.S. Department of Energy under Contract No. DEAC02-76SF00515

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Table 1: Parameters of SSRL-X

Parameters	**Value**
Circumference	571.5 m
Energy	3.5 GeV
Natural emittance (bare lattice)	63 pm
Natural emittance (with wigglers)	34 pm
Tunes (H/V)	66.20 / 20.20
Momentum compaction	1.612×10^{-4}
Natural chromaticity (H/V)	-96.56 / -92.94
Damping partition (H/V/L) (bare lattice)	2.00 / 1.00 / 1.00
Damping partition (H/V/L) (with wigglers)	1.32 / 1.00 / 1.68
Energy loss per turn (bare lattice)	0.350 MeV
Energy loss per turn (with wigglers)	1.118 MeV
Main RF voltage	3.4 MV

NONLINEAR PERFORMANCE

Dynamic Aperture and Touschek Lifetime

Dynamic aperture (DA) and Touscheck lifetime (TLT) are calculated for the bare lattice after adding 4 different error seeds leading to ~ 0.5% rms beta-beating. ELEGANT is used for tracking simulation and TLT calculation [1, 2]. Averaged dynamic aperture is 71.4 mm^2 with negative x acceptance of -12 mm which is sufficiently large to accommodate conventional off-axis injection scheme. Touscheck lifetime is 17 hours for 0.4 mA single bunch current under fully-coupled beam condition (40 pm emittance for both planes). Note that TLT is in the region where TLT increase sharply as emittance decreases (Fig. 2).

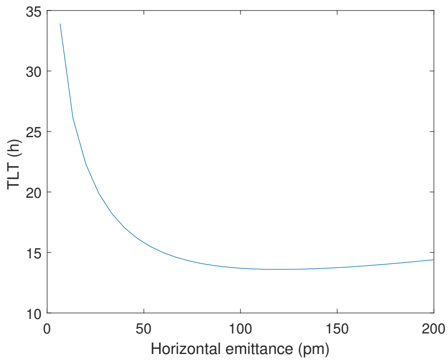

Figure 2: Touschek lifetime of bare SSRL-X as function of horizontal emittance. Full-coupling condition is assumed (vertical emittance is equal to horizontal emittance).

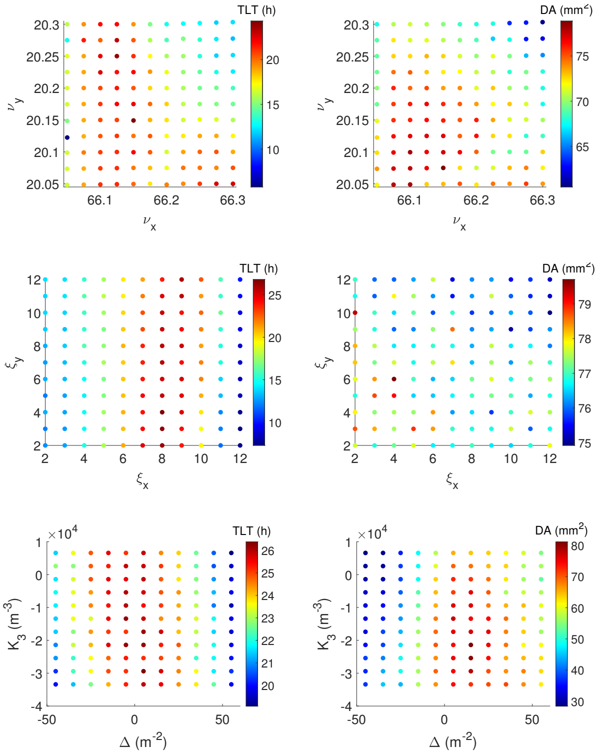

Figure 3: Series of 2D scannings for optimization of TLT and DA. Each row is result of tune scan (upper plot), chromaticity scan (middle plot), and sextupole-octupole scan (lower plot).

Optimization

Upon the original lattice configuration, series of 2D scannings are conducted in order of tune scan, chromaticity scan, and sextupole-octupole scan to find lattice configurations leading to better nonlinear performances (Fig. 3). Each scanning is done with working point selected at previous step. Through the series of 2D scannings, tune is moved to (66.15, 20.15), chromaticity is set to (8, 4), and deviation of outer sextupole strength (Δ) - octupole strength (K_3) is set to (15 m^{-2}, -21400 m^{-3}). New lattice configuration selected after optimization has DA of 81.2 mm^2 and TLT of 26 hours. DA and local momentum aperture (LMA) are compared for before and after optimization in Fig. 4. It is noticeable that TLT is increased by 53% although momentum aperture is not showing significant improvement after optimization. Further optimization using evolutionary algorithms has also been performed and the result will be reported elsewhere.

It is worth to note that TLT has strong dependence over horizontal chromaticity (Fig. 3 middle plot). This kinds of dependence was reported at ESRF-EBS before [3, 4]. It may be explained by path lengthening with betatron motion. The path lengthening with betatron motion has strong dependence on the horizontal chromaticity [5–7], and large path lengthening can introduce additional energy-offset under the synchrotron motion. The additional energy-offset can add x-offset as much as $\delta\eta_x$ which can degrade dynamic acceptance. Figure 5 shows path lengthening for varied horizontal chromaticity and path lengthening for different sextupole configurations keeping zero horizontal chromaticity. Zero horizontal chromaticity is corresponding to zero path lengthening for x offset less than 0.5 mm. Results of chromaticity scan favors horizontal chromaticity around 8 which has negative path lengthening for x offset less than 0.6 mm. Further analysis will be conducted for quantitative explanation on this.

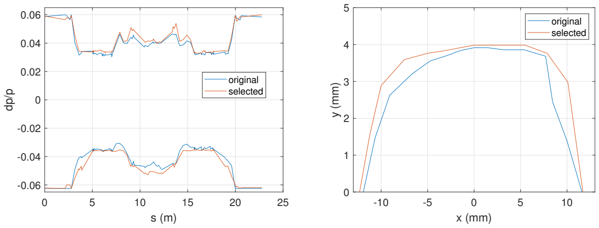

Figure 4: Comparison of momentum aperture and dynamic aperture before and after optimization. Local momentum aperture is calculated inside a one standard cell and dynamic aperture is calculated at the injection point.

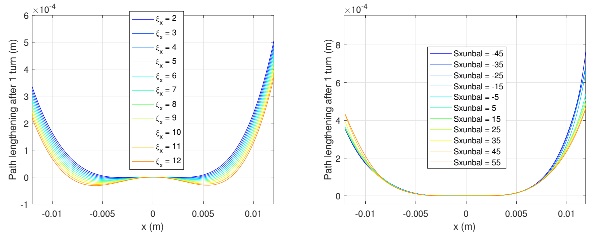

Figure 5: Path lengthening after 1 turn over initial x offset for varied horizontal chromaticity (left plot) and path lengthening after 1 turn over initial x offset for varied sextupole configurations keeping horizontal chromaticity of zero (right plot).

IBS AND EMITTANCE GROWTH

One of main factors limiting performance of low-emittance storage ring is intrabeam scattering (IBS). Since its rate is proportional to $\frac{1}{\gamma^4}$, it is expected that emittance increase under IBS is considerable for a 3.5 GeV SSRL-X storage ring. Particle tracking simulation is conducted to explore impact of IBS on emittance growth (Fig. 6). Wiggler-on and full-coupling condition is assumed. Single particle current is set to 0.5 mA. Equilibrium emittance without IBS is 18 pm for both planes. Simulation predicts emittance increase of 83% when IBS is taken into account (Fig. 6 left plot). It is suppressed to 23 pm or 28% increase when a 3rd harmonic cavity (3HC) is added (Fig. 6 right plot).

CONCLUSION

A hybrid multi-bend achromat lattice design for SSRL-X is a diffraction-limited storage ring. It provides dynamic aperture large enough to adopt conventional off-axis injection scheme. Touschek lifetime is 26 hours. Emittance growth from IBS effect can be effectively suppressed by utilizing a 3HC.

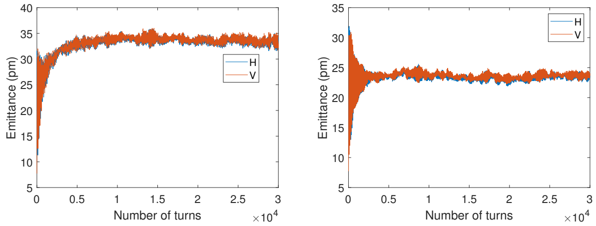

Figure 6: Emittance growth under influence of IBS. Multi-particle tracking without a 3HC (left plot) and with a 3HC (right plot).

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