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A SIX-BEND-ACHROMAT LATTICE FOR A 2.5 GeV DIFFRACTION-LIMITED STORAGE RING

J. Li*, M. Abo-Bakr, P. Goslawski
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (HZB), Berlin, Germany
Z. H. Bai†, National Synchrotron Radiation Laboratory, USTC, Hefei 230029, China

Abstract

HZB has proposed a 2.5 GeV diffraction-limited storage ring as the successor of BESSY II. A Six-Bend-Achromat lattice based on Higher-Order Achromat, as one of the possible solutions, has been designed to meet the requirements of low emittance, compact layout, large dynamic aperture and large momentum acceptance. The linear lattice design and the nonlinear performance are presented in this paper.

INTRODUCTION

BESSY II is a third-generation synchrotron radiation light source, focusing on soft X-rays. After more than 20 years successful and stable operation of BESSY II, HZB has proposed a diffraction-limited storage ring (DLSR) BESSY III as the successor of BESSY II, aiming for significant increase in brightness and coherence fraction [1]. The preliminary design study of BESSY III lattice has a goal of producing beam of ~100 pm horizontal emittance at 2.5 GeV with 16 MBA cells. In addition, the straight section for insertion devices (IDs) should be at least 5 m long, and the total circumference should not be beyond 330 m.

In parallel with the lattice studies for BESSY III at HZB [2, 3], a Six-Bend-Achromat (6BA) lattice based on Transverse Gradient Bends (TGBs) and Reverse Bends (RBs) has been designed , which is the outcome of collaborative efforts between HZB and NSRL. In each 6BA cell of this design, the Higher-Order Achromat (HOA) scheme employs four repetitive cells with distributed chromatic sextupoles and fixed phase advances in horizontal and vertical planes to suppress main geometric and some chromatic resonances [4]. Distinct from the designs in [2, 3], particular emphasis has been placed on the large Dynamic Aperture (DA) for off-axis injection.

THE 6BA LATTICE WITH REVERSE BENDS AND TRANSVERSE-GRADIENT BENDS

The studies in [5–9] have led the trend in lattice designs for DLSRs in recent years. The lattice candidates for a 2.5 GeV DLSR have been analyzed in detail and compared in [10], the possible options can be based on ESRF-EBS hybrid 7BA, 6BA and SLS2 7BA lattices. Considering the compact layout of BESSY III, the 6BA with TGBs and RBs is a proper trade-off between emittance and circumference.

Following the 6BA design in [11], we adopt the major design concept and replace the longitudinal gradient bends (LGBs) and defocusing quadrupoles with TGBs. Furthermore, the quadrupole triplets are replaced by doublets for compact space and improvement of nonlinear dynamics. The 6BA lattice in this paper has 16 straights of 5 m length. Each 6BA cell consists of four unit cells and two matching cells. Each unit cell has a ~5° TGB and two ~−0.3° RBs, while each matching cell at the ends of the achromat has a ~2.47° TGB. All the TGBs contain a vertical focusing gradient, and the RBs contain a horizontal focusing gradient. The quadrupole doublets in the matching cells are used to match the achromat optics to the straight sections. The high values of the horizontal beta function in the straight sections are chosen for off-axis injection, however, not taking into account the optimal phase-space match of electron and photon beams.

Following the HOA scheme, the horizontal and vertical phase advances of each unit cell are fixed at ~ $0.4 \times 2\pi$ and ~ $0.1 \times 2\pi$, respectively [4]. Correspondingly, the betatron tunes of each 6BA cell are chosen in the vicinity of (2.625, 0.875) so that the main geometric and some chromatic resonances can be further cancelled over 8 lattice cells. The linear optics of one achromat is displayed in Fig. 1, and the main parameters of the designed storage ring are given in Table 1.

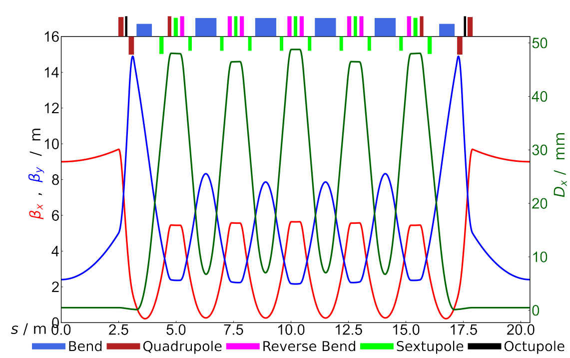

Figure 1: Linear optics of the 6BA lattice.

NONLINEAR BEAM DYNAMICS

The storage ring contains two focusing sextupole families and two defocusing families to correct natural chromaticites. The sextupole optimization was performed with OPA [12] as the starting point. The linear chromaticities were corrected to + 2.0 in both planes, and geometric Resonance Driving Terms (RDTs) along with higher-order chromaticites were

* ji.li@helmholtz-berlin.de
† baizhe@ustc.edu.cn

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Table 1: Parameters of the 2.5 GeV Storage Ring

Parameter	Value
Energy	2.5 GeV
Circumference	326.4 m
Working point (H/V)	41.380 / 13.205
Natural chromaticities (H/V)	-84.69 / -48.39
Radiation loss per turn	363.7 keV
Damping partition (H/V/L)	1.846 / 1.0 / 1.154
Damping time (H/V/L)	8.110 / 14.967 / 12.964
Natural emittance	115 pm
Natural energy spread	8.49×10^{-4}
Momentum compaction	1.02×10^{-4}
β_x, β_y @ straight section center	9.0/ 2.4 m

minimized with the integrated optimizer in OPA. In order to suppress the Amplitude-Dependent Tune Shifts (ADTS), one octupole family has been placed inside the quadrupole doublets in the matching cells.

The more sophisticated nonlinear dynamics optimization was performed by using Elegant [13] based on the optimization results from OPA. The sextupole and octupole strengths, as well as their positions were further optimized to enlarge the DAs at different energy. In the mean time, we set constraints in optimizations to leave enough space between magnets. The effective DA, the major objective in the nonlinear dynamics optimization, is defined as the area taken up by the survived particles after tracking 1024 turns with Elegant, and the particles which have crossed the integer or half-integer resonances are treated as lost ones.

As shown in the frequency map in Fig. 2(a), the optimized sextupole and octupole settings result in large on-momentum DA ~$\pm$10 mm, which ensures high injection efficiency with off-axis injection scheme and accordingly demonstrates the ADTS are well controlled. The tunes of those particles close to x = 0 axis sometimes cannot be correctly identified by Elegant due to strong nonlinear coupling, so the corresponding two broad vertical resonance lines don't reflect the reality. The tune footprint in Fig. 2(b) confirms the compact tune shifts of the survived particles.

As depicted in Fig. 3, the chromatic tune shifts are limited in the range of [-0.141,0.020] horizontally and [-0.023,0.163] vertically when the energy deviation varies from -5‰ to +5‰ . Accordingly, the DAs plotted in Fig. 4 are large at various energy deviations, which yields large momentum acceptance.

PARAMETERS OF MAGNETS

The feasibility of magnets used in the lattice should also be considered, and we avoid using the magnets which are very challenging to design and manufacture. We set constraints for magnets in lattice optimizations: the strengths of main dipoles should not be higher than 1 T, and the quadrupole strength of the reverse bends and quadrupoles should be blow 60 T/m. In addition, the strength of sextupoles and the octupole should be below 6 000 T/m^2 and 100 000 T/m^2.

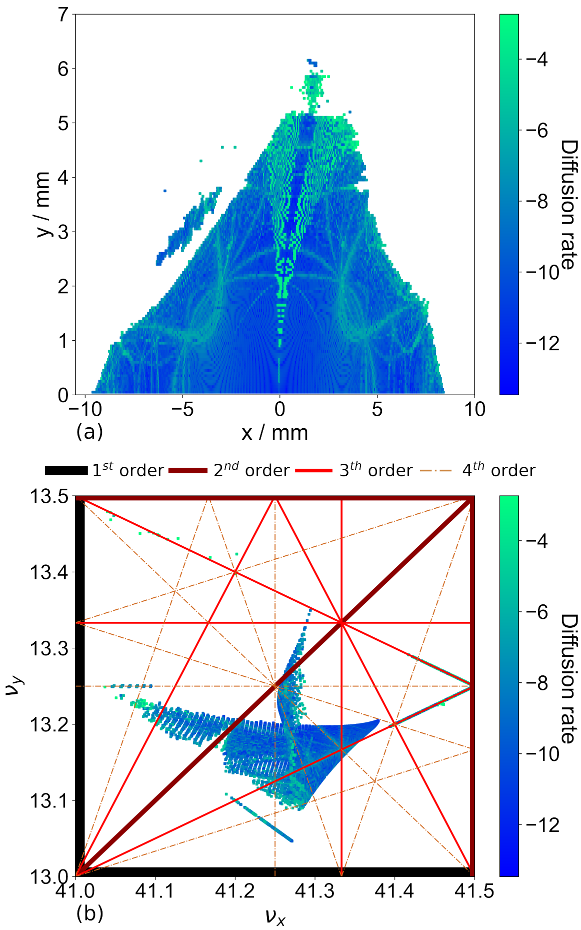

Figure 2: Frequency map analysis extracted from 1024-turn tracking using Elegant: (a) dynamic aperture with diffusion rates, (b) tune footprint.

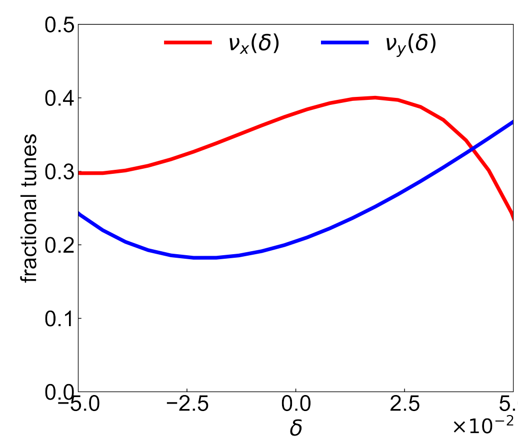

Figure 3: Chromatic tune shifts.

As shown in Fig. 5, the strength of the dipole in the matching cell is 0.55 T and 0.81 T in the unit cell, respectively. Correspondingly the maximum transverse gradient in the dipoles is 11.44 T/m. The dipole strength of the reverse bends is ~0.29 T, while their quadrupole strength is ~51 T/m. The maximum quadrupole strength of the pure quadrupoles is ~56 T/m.

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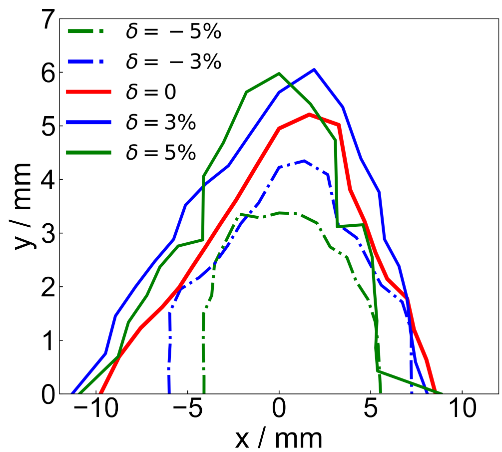

Figure 4: Dynamic apertures at various energy deviations.

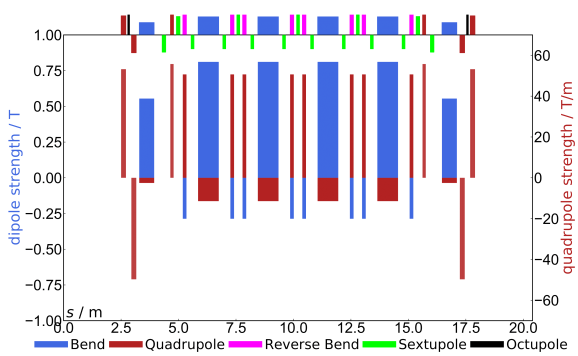

Figure 5: Dipole and quadrupole strengths.

As plotted in Fig. 6, the maximum sextupole strength is ~5 700 T/m^2, and the strength of the octupole is ~38 000 T/m^3.

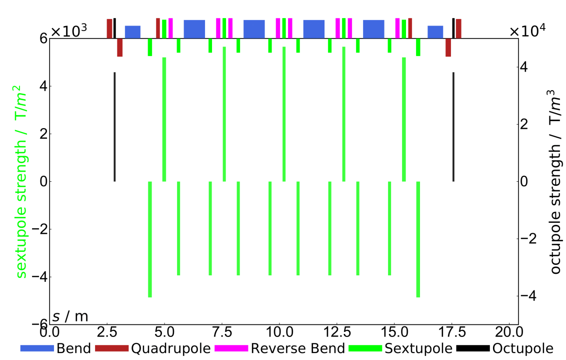

Figure 6: Sextupole and octupole strengths.

SUMMARY

The HOA 6BA lattice has been designed for a 2.5 GeV DLSR, which can be a potential candidate for BESSY III. This approach allows off-axis injection due to the large DA. However, it has not satisfied all the requirements of BESSY III yet, such as longer straight sections, homogeneous dipole radiation for specific beamlines, and low-beta straight sections and so on. As a robust starting point, this lattice can be further optimized.

To approach the design specifications of BESSY III, we will consider to minimize the transverse gradient in the dipoles of the matching cells to 0 for specific users. Moreover, a detailed study will analyze the optimal phase-space match of electron and photon beams and will result in an overall optimization of all parameters.

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