ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-THPAB073

STUDY OF SEVEN-BEND-ACHROMAT LATTICE OPTION FOR HALF

Jianhao Xu, Zhiliang Ren, Jiajie Tan, Penghui Yang*, Zhenghe Bai†
National Synchrotron Radiation Laboratory, USTC, Hefei, China
Qingkun Zhang
Institute of Nuclear Energy Safety Technology, Chinese Academy of Science, Hefei, China

Abstract

A seven-bend-achromat (7BA) storage ring lattice design for Hefei Advanced Light Facility (HALF) with a beam energy of 2.2 GeV and a circumference of 388.8 m is presented. The 7BA lattice is designed with the combined function bends and reverse bends which has a natural emittance of about 67 pm·rad. Two lattice candidates with different tunes have been selected. One lattice has better nonlinear dynamic performance for off-axis injection. The other lattice provides lower beta functions at the center of straight sections. The results of these studies are discussed in this paper.

INTRODUCTION

The hybrid multi-bend achromat (MBA) lattice has been used in many diffraction-limited storage ring (DLSR) designs since it was proposed by ESRF-EBS [1]. It can achieve a relatively low emittance and excellent nonlinear performance. To further reduce the emittance, reverse bends have been used in some MBA lattice designs [2–5]. The reverse bend increases the energy loss per turn, thus potentially reducing emittance. It can adjust the dispersion function better and it allows control of the damping partition numbers [5].

A 7BA lattice, based on a hybrid seven-bend achromat [6], is designed for HALF with the combined function bends and reverse bends. To control the nonlinear dynamics, -I transformation and higher-order achromat approaches are adopted. The horizontal and vertical phase advances between the two dispersion bumps are $(3\pi, \pi)$. The tunes in one lattice cell are set to (2.4, 0.9) or (2.6, 0.9) to ensure that a number of nonlinear terms can be eliminated in five lattice cells. Then two lattice candidates with different tunes are studied. One has a better nonlinear dynamic performance aiming for off-axis injection. The other has a smaller dynamic apeture (DA) but the beta functions are lower at the center of straight sections.

7BA LATTICE DESIGN

The type of lattice designed in this paper has a beam energy of 2.2 GeV and a circumference of 388.8 m which consists of 20 identical cells with the straight section length of 5 m. Unlike the typical hybrid MBA lattice, this lattice does not use longitudinal gradient bending magnet. All bends are combined function bends with transverse gradient. At the same time, for reducing the emittance further, two families of quadrupoles in the high-dispersion region and the central region were converted into reverse bending magnets.

The linear lattice was designed and optimized considering -I transformation and higher-order achromat approaches. The lattice was firstly optimized to have small emittance and the sum of the integral strengths of three families of sextupoles [7]. Then the nonlinear dynamic performance of the lattice was further optimized using three families of sextupoles and one or two families of octupoles. Two lattice candidates with different tunes have been summarized below.

Case 1: Off-axis Injection Lattice

The first lattice was optimized for off-axis injection. The linear optical functions and magnet layout of one cell are shown in Fig. 1. The dipole field of all bends are below 0.55 T. The transverse gradients of reverse bends are below 50 T/m and the transverse gradients of the other combined function bends are below 25 T/m. The maximum strength of quadrupoles reaches 65 T/m. The main parameters of the storage ring are listed in Table 1. The nonlinear dynamic performance was optimized based on three sextupole families and one octupole family. In the optimization, chromaticities were corrected to (3, 3) in view of increasing the dynamic momentum aperture.

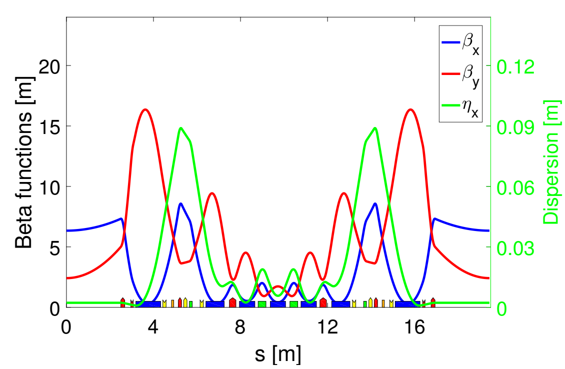

Figure 1: Linear optical functions and magnet layout (case 1). Bends are in blue, reverse bends in green, quadrupoles in red, sextupoles in yellow and octupole in brown.

Initial results of on-momentum DA and frequency map analysis (FMA) optimized for this lattice are shown in Fig. 2. We can see that the horizontal DA is large enough for off-axis injection, and the vertical DA is also large enough. Figure 3 shows the momentum dependent tune footprints.

Case 2: Low-beta Lattice

The second lattice was optimized with lower beta functions at the center of straight sections. The linear optical functions and magnet layout of one cell are shown in Fig. 4.

* penghui1@mail.ustc.edu.cn
† baizhe@ustc.edu.cn

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-THPAB073

Table 1: Main Parameters of Two Storage Ring Designs for Case 1 and Case 2

Parameters	**Case 1**	**Case 2**
Nat. emittance (pm)	67.1	67.4
Betatron tunes	48.20/17.21	52.31/18.32
Nat. chrom	-73.6/-58.4	-89.1/-89.1
Mom. comp	1.21E-04	1.15E-04
Energy loss (keV)	156.0	170.2
Damping times (ms)	16/37/46	15/34/42
ID Straight Sections:		
Beta functions (m)	6.34/2.32	1.62/1.42

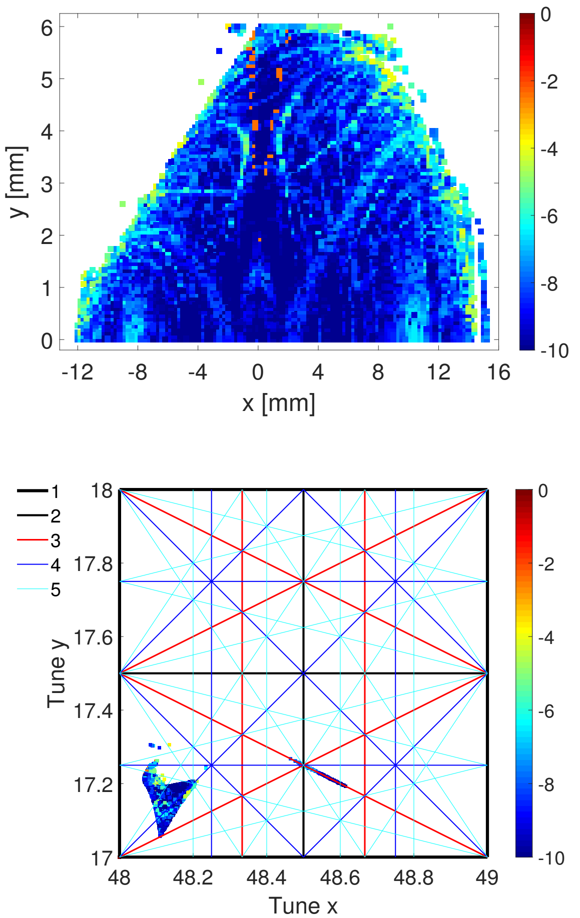

Figure 2: FMA of the optimized DA (case 1).

Compared with case 1, the strengths of the magnets are increased. The gradient of reverse bend in central region reaches 60 T/m. The maximum strength of quadrupoles reaches 75 T/m. Three families of sextupoles and two families of octupoles were used to optimize the nonlinear dynamic performance and chromaticities were corrected to (3, 3). The family of octupole placed in dispersion-free region is mainly used to control the amplitude dependent tune shifts. The family of octupole placed in dispersion bump region is used to adjust the high-order chromaticities. Figure 5 shows the momentum dependent tune footprints. Figure 6 shows the FMA of this lattice. We can see that the horizontal DA is about 3 mm. Figure 7 shows the horizontal DAs for momentum deviations from −4% to 4%.

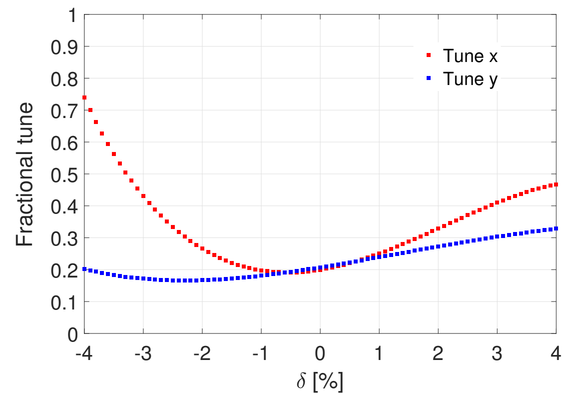

Figure 3: Momentum dependent tune footprints (case 1).

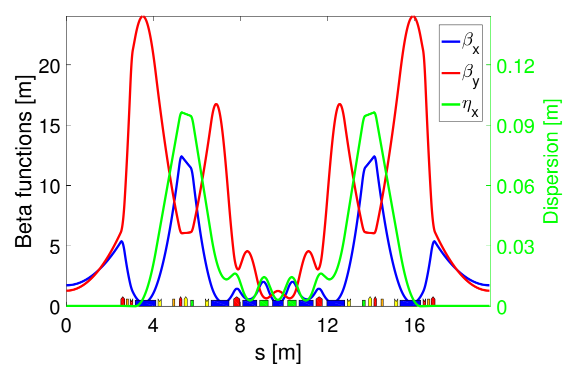

Figure 4: Linear optical functions and magnet layout (case 2).

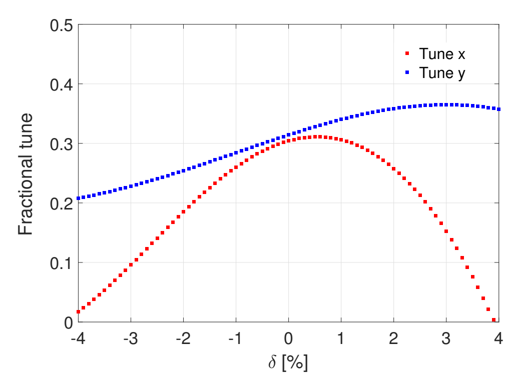

Figure 5: Momentum dependent tune footprints (case 2).

CONCLUSION

A type of 7BA lattice has been designed with the combined function bends and reverse bends. Two lattices with different tunes scheme are presented. The lattice with small tunes has better nonlinear dynamic performance compared

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-THPAB073

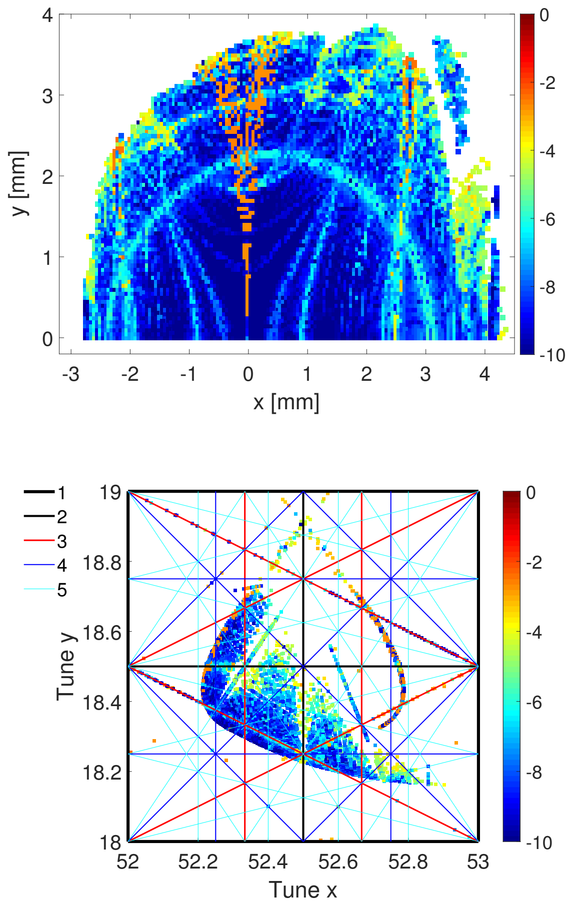

Figure 6: FMA of the optimized DA (case 2).

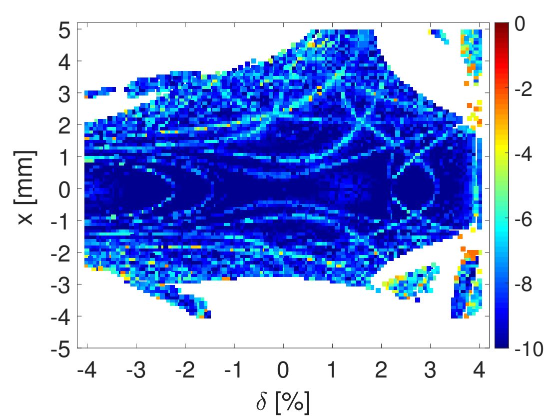

Figure 7: Horizontal DAs for momentum deviations from −4% to 4% (case 2).

to the lattice with large tunes. But the other with large tunes has lower beta functions at the center of straight sections, which means higher brightness can be achieved. At present, two lattice candidates are still in the process of optimization, and more results will be further discussed in the future.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (11875259, 11805229) and the National Key Research and Development Program of China (2016YFA0402000).

REFERENCES

[1] L. Farvacque *et al.*, "A Low-Emittance Lattice for the ESRF", in *Proc. 4th Int. Particle Accelerator Conf. (IPAC'13)*, Shanghai, China, May 2013, paper MOPEA008, pp. 79–81.

[2] B. Riemann and A. Streun, "Low emittance lattice design from first principles: Reverse bending and longitudinal gradient bends", *Phys. Rev. Accel. Beams*, vol. 22, p. 021601, 2018. doi:10.1103/PhysRevAccelBeams.22.021601

[3] A. Streun, "The anti-bend cell for ultralow emittance storage ring lattices", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 737, pp. 148-154, 2014. doi:10.1016/j.nima.2013.11.064

[4] P. Yang, W. Li, Z. Ren, Z. Bai, and L. Wang, "Design of a diffraction-limited storage ring lattice using longitudinal gradient bends and reverse bends", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 990, p. 164968, 2021. doi:10.1016/j.nima.2020.164968

[5] M. Borland, T. G. Berenc, R. R. Lindberg, V. Sajaev, and Y. P. Sun, "Lower Emittance Lattice for the Advanced Photon Source Upgrade Using Reverse Bending Magnets", in *Proc. North American Particle Accelerator Conf. (NAPAC'16)*, Chicago, IL, USA, Oct. 2016, pp. 877–880. doi:10.18429/JACoW-NAPAC2016-WEPOB01

[6] A. Loulergue *et al.*, "Baseline Lattice for the Upgrade of SOLEIL", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 4726–4729. doi:10.18429/JACoW-IPAC2018-THPML034

[7] P. Yang, Z. Bai, T. Zhang, D. Xu, L. Wang, "Design of a hybrid ten-bend-achromat lattice for a diffraction-limited storage ring light source", *Nucl. Instrum. Methods Phys. Res., Sect. A*, vol. 943, p. 162506, 2019. doi:10.1016/j.nima.2019.162506