ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB112

A MODIFIED HYBRID 6BA LATTICE FOR THE HALF STORAGE RING

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Abstract

In this paper, we propose a modified hybrid 6BA lattice as the baseline lattice of the Hefei Advanced Light Facility (HALF) storage ring. Similar to the Diamond-II lattice, the proposed lattice cell has one long straight section and one mid-straight section; but the two bend units adjacent to the mid-straight are LGB/RB units (LGB: longitudinal gradient bend, RB: reverse bend), which can give both lower emittance and shorter damping times. The designed HALF storage ring, with an energy of 2.2 GeV and 20 lattice cells, has a natural emittance of about 85 pm·rad.

INTRODUCTION

Hefei Advanced Light Facility (HALF) is a soft X-ray and VUV diffraction-limited storage ring being designed by NSRL, which has the natural emittance goal of lower than 100 pm·rad. Considering both the main radiation region of interest and suppression of the emittance increase due to intra-beam scattering (IBS) effect, the beam energy of the HALF storage ring was determined to be 2.2 GeV. The HALF storage ring also wanted to have more long straight sections for insertion devices. Recently some multi-bend achromat (MBA) lattices have been studied and designed for the HALF storage ring. From the emittance goal point of view, the design with 16 cells of 6BA lattice with distributed chromaticity correction [1] or the one with 20 cells of hybrid 7BA lattice [2] can be adopted. Considering that the hybrid 7BA lattice provides larger dynamic aperture (DA) for off-axis injection and more long straight sections, it is a relatively preferred option for HALF.

For the design with 20 cells of hybrid 7BA lattice, the natural damping times are relatively long (about 50 ms in the vertical plane), resulting in serious emittance increase when including IBS. Introducing reverse bends (RBs) in the lattice, as done in the APS-U lattice, can reduce the damping times as well as the emittance. In this paper, we propose a modified hybrid 6BA lattice for HALF, which can not only reduce the damping times and emittance but also provide an additional straight section for insertion device. This new lattice has been determined to be the baseline lattice of HALF.

LATTICE CONCEPT

Figure 1 shows the schematic of the modified hybrid 6BA lattice concept we proposed. In this new lattice, two LGB/RB unit cells (LGB: longitudinal gradient bend) and a mid-straight replace the three combined-function bend unit cells in the central part of the ESRF-EBS hybrid 7BA lattice [3]. Compared to the unit cell with uniform dipole field, the unit cell with LGB and RB (used in the SLS-2 lattice) can have lower emittance and more radiation loss [4]. So compared to the Diamond-II modified hybrid 6BA lattice [5] which also has an additional mid-straight, this new lattice can give lower emittance and shorter damping times. In a nutshell, this new lattice concept combines the merits of ESRF-EBS lattice, SLS-2 lattice and Diamond-II lattice, thus providing large DA, relatively low emittance, relatively short damping times and an additional straight section.

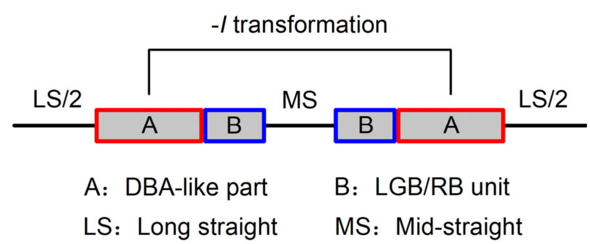

Figure 1: Schematic of the modified hybrid 6BA lattice concept.

LATTICE DESIGN AND OPTIMIZATION

Linear Lattice Design

The proposed lattice has been applied to the HALF storage ring design, which has 20 identical cells. Figure 2 shows the magnet layout and linear optical functions of the designed HALF lattice. As in the ESRF-EBS lattice, the horizontal and vertical phase advances between two dispersion bumps are about 3π and π, respectively, for very effective nonlinear cancellation. The six main bends of the lattice are all LGBs. There are two families of combined-function RBs near the 3rd and 4th LGBs with defocusing quadrupoles close to them. The long straight section is 5.5 m long and the mid-straight is 2.2 m long. Table 1 lists the main parameters of the designed HALF storage ring. The natural emittance is 85.5 pm·rad, and the vertical damping time is about 35 ms. The transverse tunes are situated on linear coupling resonance for producing round beams. The horizontal and vertical tunes of each lattice cell are near (2.4, 0.9), so that main resonance driving terms caused by sextupoles can be further minimized over 5 lattice cells. The dipole field profiles of LGBs are shown in Fig. 3. The RB between the 2nd and 3rd LGBs has dipole field of 0.325 T and gradient of 45.9 T/m, and they are 0.221 T and 51.6 T/m for the RB adjacent to the mid-straight.

If the Diamond-II modified hybrid 6BA lattice (CDR version) [6] is scaled to the HALF case with 2.2 GeV and 20 cells, the natural emittance will be about 110 pm·rad

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ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB112

and the vertical damping time will be about 45 ms, which are all larger or longer than those of the HALF modified hybrid 6BA lattice. Besides, though the HALF lattice is 6BA, its natural emittance is almost the same as that of the hybrid 7BA lattice design (without RBs) [2].

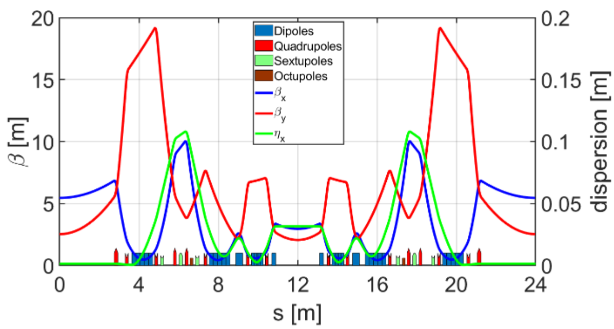

Figure 2: Magnet layout and linear optical functions of the HALF modified hybrid 6BA lattice.

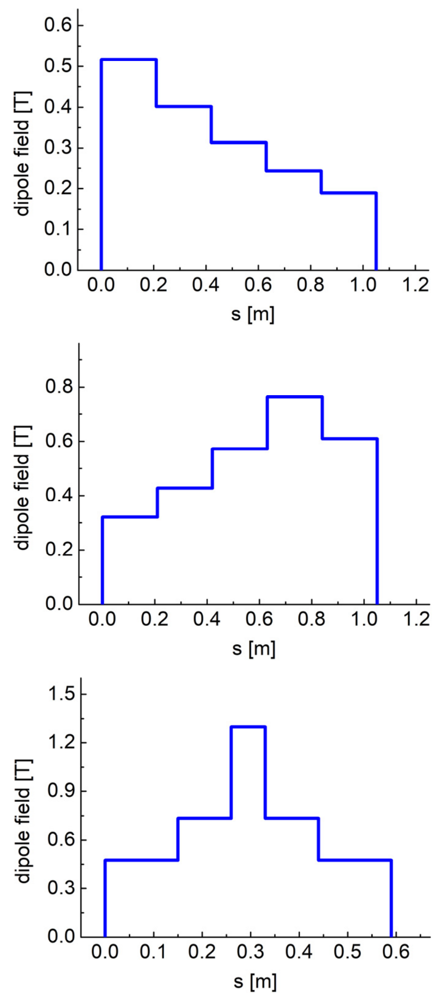

Figure 3: Dipole field profiles of the first (upper), second (middle) and third (lower) LGBs.

Table 1: Main Parameters of the HALF Storage Ring

Parameter	Value
Energy	2.2 GeV
Circumference	480 m
Number of cells	20
Natural emittance	85.5 pm·rad
Transverse tunes (H/V)	48.16/17.16
Natural chromaticities (H/V)	-75/-59
Momentum compaction factor	8.1×10^{-5}
Damping partitions (H/V/L)	1.44/1.0/1.56
Natural damping times (H/V/L)	24.6/35.4/22.7 ms
Natural energy spread	0.65×10^{-3}
Energy loss per turn	198.8 keV
Total absolute bending angle	458.6°
β_x, β_x and η @ long straight	5.46, 2.53, 0.001 m
β_x, β_x and η @ mid-straight	2.96, 2.06, 0.032 m

Nonlinear Dynamics Optimization

The nonlinear dynamics was optimized with three families of sextupoles and one family of octupoles, and the horizontal and vertical chromaticities were corrected to (4, 4). It was found that the positions of defocusing sextupoles have a big impact on the nonlinear dynamics performance. The optimized DA is shown in Fig. 4, which is larger than 10 mm in the horizontal plane and thus can allow off-axis injection. The tune shifts with horizontal amplitude are shown in Fig. 5, and we see that the fractional tunes are separated at large amplitude, avoiding the coupling of large horizontal motion to the vertical plane during off-axis injection. When RF cavity and errors are included, the horizontal DA has an obvious reduction. To ensure a large enough DA for off-axis injection, a special long straight section will be designed with larger horizontal beta function, as done in the ESRF-EBS lattice.

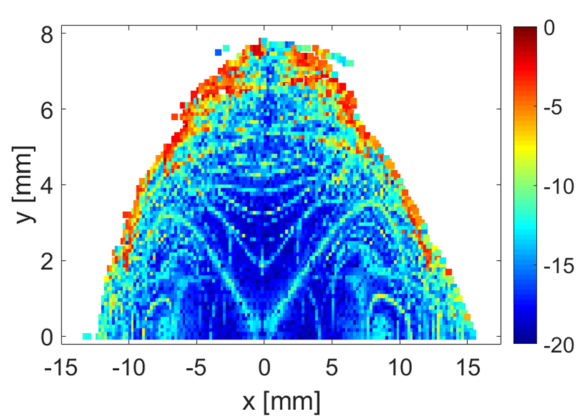

Figure 4: On-momentum DA. The color bar represents the diffusion rate.

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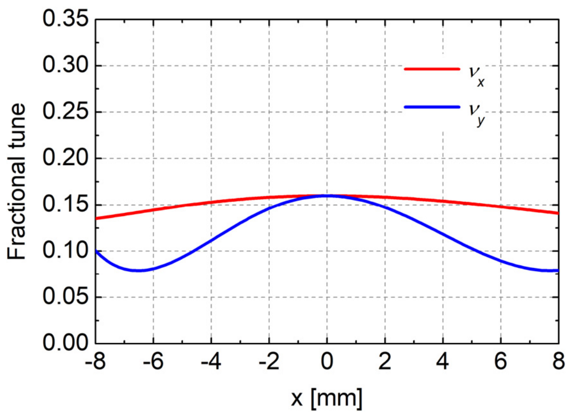

Figure 5: Tune shifts with horizontal amplitude.

The dynamic momentum acceptance is larger than 4% as shown in Fig. 6. Figure 7 shows the horizontal DAs at relative momentum deviations of -4%~4%. With RF cavity of 500 MHz and beam current of 400 mA, the Touschek lifetime is about 5 hours for 10%-coupling beams without bunch lengthening. In the case of full-coupling beams with bunches lengthened by a factor of 5, the Touschek lifetime is much longer than 10 hours.

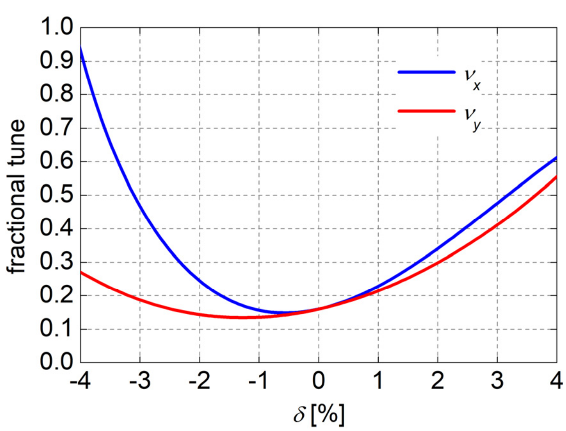

Figure 6: Tune shifts with momentum.

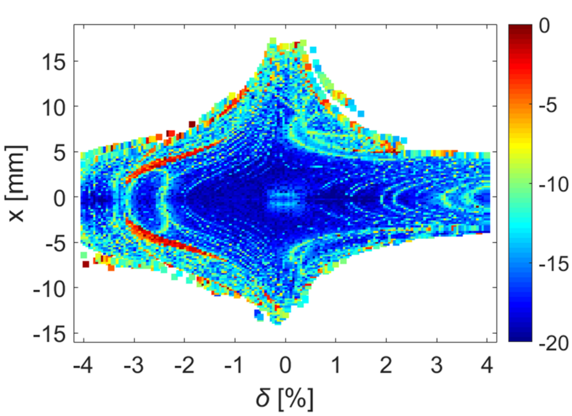

Figure 7: Horizontal DAs at relative momentum deviations of -4%~4%.

INTRA-BEAM SCATTERING EFFECT

As the beam emittance is reduced towards the diffraction-limited emittance, the dipole fields tend to be weaker and the storage ring circumference tends to be larger, which will result in longer damping time. Lower emittance together with longer damping time will make the IBS effect more serious, causing significant emittance increase. With LGB/RB units used in the lattice, the natural damping time of HALF was controlled to some extent. However, compared to most of third-generation synchrotron light sources, the damping time of HALF is still relatively long. Even with full-coupling and lengthened bunches, the emittance of HALF still increases by 50%~60% due to IBS. With two long straight sections equipped with damping wigglers, the round beam emittance can be reduced to 50~60 pm·rad.

CONCLUSION

A modified hybrid 6BA lattice has been proposed as the baseline lattice of HALF, which combines the merits of ESRF-EBS lattice, SLS-2 lattice and Diamond-II lattice. The designed HALF storage ring has a natural emittance of about 85 pm·rad. Further design and optimization of the lattice is ongoing.

ACKNOWLEDGEMENTS

The authors would like to thank Dieter Einfeld and Ryutaro Nagaoka for discussing the lattice presented here during they visited NSRL at the end of 2019. This work was supported by the National Natural Science Foundation of China (11875259) and the National Key Research and Development Program of China (2016YFA0402000).

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