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STUDY OF MULTI-BEND ACHROMAT LATTICES FOR THE HALS DIFFRACTION-LIMITED STORAGE RING

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Abstract

In this paper, two multi-bend achromat (MBA) lattice concepts, the locally symmetric MBA and MBA with interleaved dispersion bumps, are described, which have been used to design the Hefei Advanced Light Source (HALS), a soft X-ray diffraction-limited storage ring proposed at NSRL. In these two MBA concepts, most of the nonlinear effects caused by sextupoles can be cancelled out within one lattice cell as in the hybrid MBA proposed by ESRF EBS, but the available family number of sextupoles in one cell can be more than that in the hybrid MBA so that, for example, the tune shift with momentum can be better controlled to increase the dynamic momentum aperture (MA). Using the two MBA concepts, three kinds of lattices, 8BA, 6BA and 7BA, have been studied for the HALS, showing large on- and off-momentum dynamic apertures and large enough dynamic MA.

INTRODUCTION

Hefei Light Source (HLS) was a second-generation synchrotron light source at NSRL, which was operated in 1991. After about 20 years' operation, HLS started a major upgrade to improve its performance, which was successfully finished in 2014. After the upgrade, the beam emittance was reduced from 160 nm·rad to 40 nm·rad, and the number of the straight sections for insertion devices was increased to 6. Also after the upgrade, a proposal was put forward at NSRL to build a new soft X-ray diffraction-limited storage ring, which was named Hefei Advanced Light Source (HALS). At present, the beam energy of the HALS storage ring is chosen to be 2.4 GeV, and the beam emittance is aimed at less than 50 pm·rad.

The HALS storage ring lattice was initially designed [1] following the main feature of the hybrid multi-bend achromat (MBA) concept proposed by ESRF EBS [2]. But due to the limited families of sextupoles that can be used in one cell, it is hard to increase the dynamic MA. So we considered to develop other MBA concepts, in which not only the nonlinear cancellation can be done within one cell as in the hybrid MBA, but also the family number of sextupoles that can be used in one cell can be more than 3.

LOCALLY SYMMETRIC MBA LATTICES FOR HALS

In the locally symmetric MBA lattice concept [3], the beta functions of each cell are made locally symmetric about two mirror planes, between which the phase advances satisfy:

$$\mu_x=(2m+1)\pi,\ \mu_y=n\pi, \tag{1}$$

as shown in Fig. 1. The sextupoles are also placed locally symmetric about the two mirror planes so that most of the nonlinear effects can be cancelled out within one cell, and there can be placed many families of sextupoles in this lattice. According to the position of the midplane in Fig. 1, the locally symmetric MBA can be classified into two kinds. If the midplane is at the middle of the arc section, it is called the first kind; while if the midplane is at the middle of the long straight section, it is called the second kind.

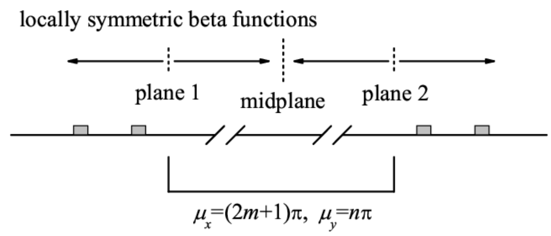

Figure 1: Schematic of locally symmetric MBA lattice.

The locally symmetric MBA of the first kind was used to design an 8BA lattice for the HALS storage ring, and the second kind was used to design a 6BA, which are shown in Fig. 2 and Fig. 3, respectively. Table 1 lists their main parameters. In the 8BA lattice, seven families of sextupoles and one family of octupole were employed for nonlinear dynamics optimization, and the 6BA lattice had five families of sextupoles and two families of octupoles. The nonlinear optimization results of the 8BA lattice with chromaticities corrected to (1, 1) are shown in Fig. 4, Fig. 5 and Fig. 6. The optimized DA is about 150 sigma; the dynamic MA at long straight sections is larger than 7%; and the off-momentum DAs are also large. In addition, from Fig. 5 we can see that if the chromaticities are corrected to slightly higher values, the dynamic MA can be further increased. The nonlinear optimization results of the 6BA lattice are also rather good, see Ref. [3].

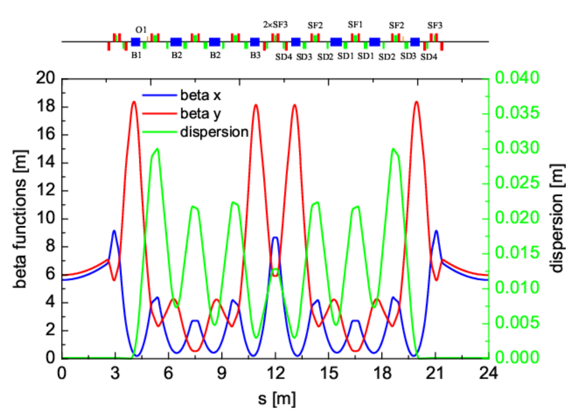

Figure 2: The HALS 8BA lattice.

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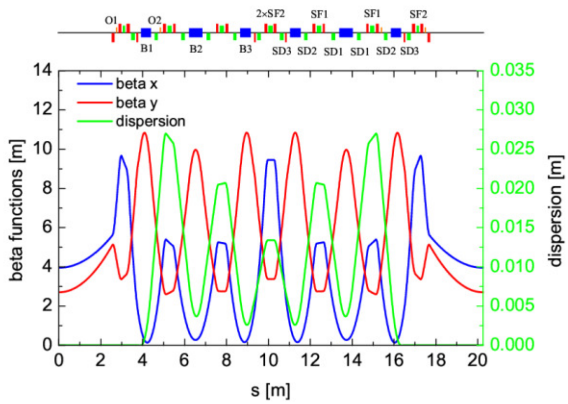

Figure 3: The HALS 6BA lattice.

Table 1: Main Parameters of the HALS 8BA and 6BA Lattice Rings

Parameter	8BA	6BA
Energy	2.4 GeV	2.4 GeV
Circumference	576 m	648 m
Number of cells	24	32
Natural emittance	35.8 pm·rad	26.5 pm·rad
Transverse tunes	76.205, 27.258	88.374, 23.284
Natural chromaticities	-136, -116	-204, -100
Momentum compaction factor	5.96×10^{-5}	3.42×10^{-5}
Beta functions at long straights	5.632, 5.977 m	3.904, 2.761 m

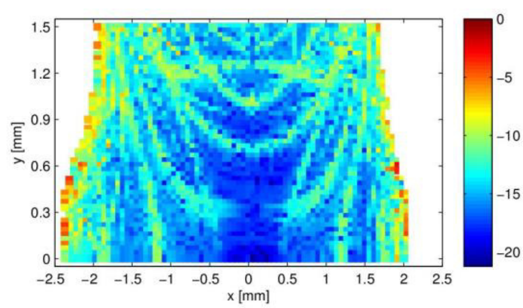

Figure 4: The optimized DA of the HALS 8BA lattice.

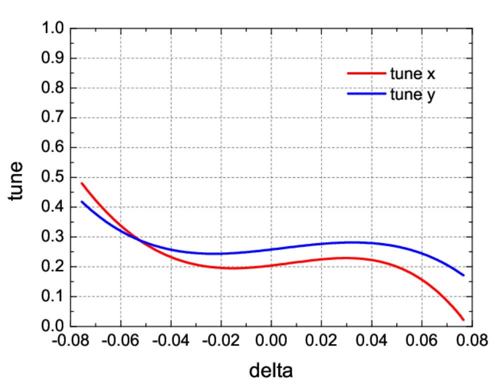

Figure 5: Tunes vs. momentum offset of the HALS 8BA lattice.

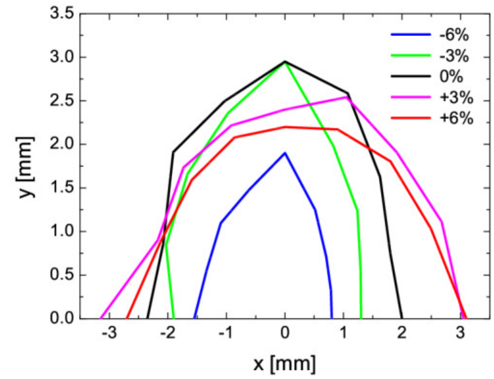

Figure 6: Off-momentum DAs of the HALS 8BA lattice.

7BA LATTICE WITH INTERLEAVED DISPERSION BUMPS FOR HALS

Inspired by the hybrid 7BA and the locally symmetric 6BA, we proposed a second MBA concept, the MBA with interleaved dispersion bumps [4]. In this concept, two pairs of dispersion bumps are created in each cell, which are interleaved from the nonlinear cancellation point of view, as shown in Fig. 7. Following this concept, a 7BA lattice was designed for the HALS storage ring, which is shown in Fig. 8, and the main parameters of the 7BA lattice ring are listed in Table 2. Six families of sextupoles, three in each pair of bumps, were employed for nonlinear optimization, and the chromaticities were corrected to (3, 3). The optimized DA is about 200 sigma, and the dynamic MA at long straight sections is about 8%, see Fig. 9 and Fig. 10, respectively. From Fig. 11 we can see that the off-momentum horizontal DAs are also large.

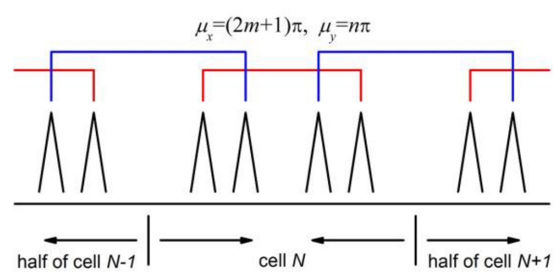

Figure 7: Schematic of MBA lattice with interleaved dispersion bumps.

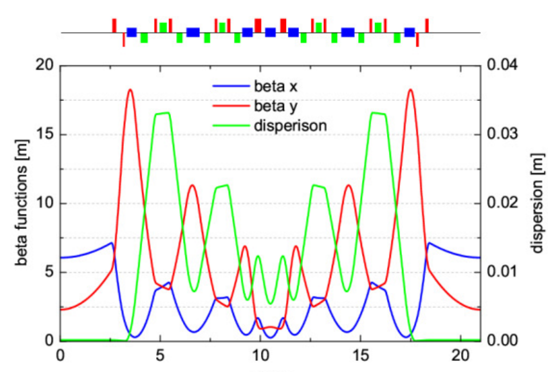

Figure 8: The HALS 7BA lattice.

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Table 2: Main Parameters of the HALS 7BA Lattice Ring

Parameter	Value
Energy	2.4 GeV
Circumference	672 m
Number of cells	32
Natural emittance	32.1 pm·rad
Transverse tunes	78.273, 29.345
Natural chromaticities	-103, -117
Momentum compaction factor	5.75×10^{-5}
Beta functions at long straights	6.068, 2.299 m

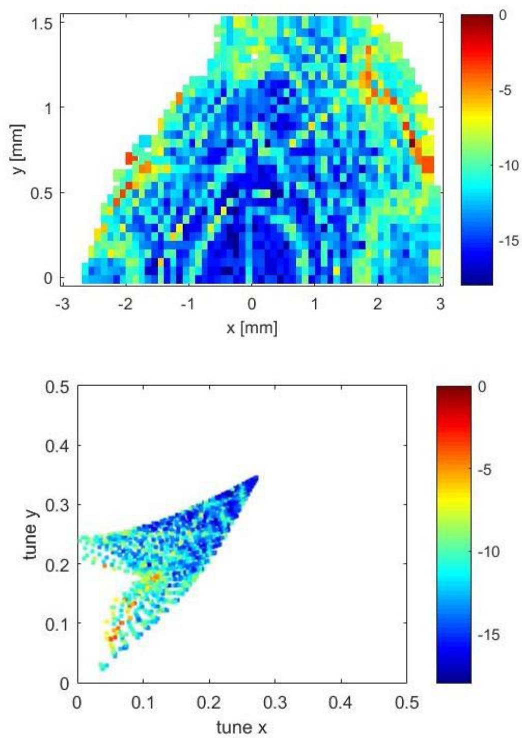

Figure 9: Frequency map analysis for the optimized DA of the HALS 7BA lattice.

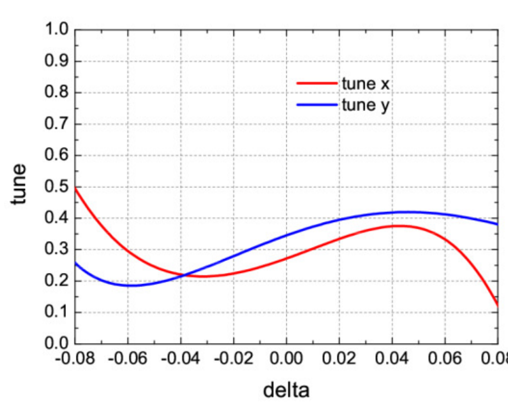

Figure 10: Tunes vs. momentum offset of the HALS 7BA lattice.

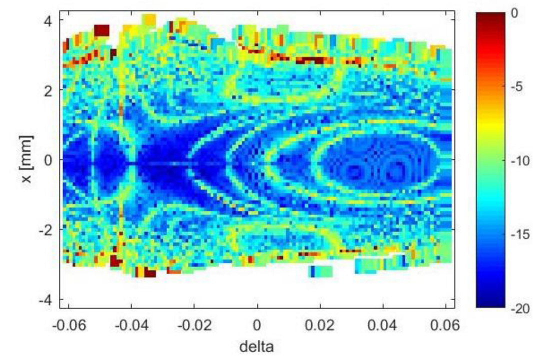

Figure 11: Horizontal DAs vs. momentum offset of the HALS 7BA lattice.

CONCLUSION AND OUTLOOK

Two MBA lattice concept, the locally symmetric MBA and MBA with interleaved dispersion bumps, have been described, which follow the same philosophy, i.e. doing nonlinear cancellation within one cell and also having many knobs to be used in one cell. Three lattices, an 8BA, a 6BA and a 7BA, have been designed with natural emittances of about 30 pm·rad for the HALS storage ring using these two MBA concepts. The optimized nonlinear dynamics results for these three lattices were rather good, showing large on- and off- momentum DAs and large enough dynamic MA (larger than 7%), which could not only guarantee a very long beam lifetime, but also promise the implementation of longitudinal injection [5] for the HALS. Besides, at present a lower-emittance 7BA lattice with longitudinal and reverse bending magnets is being studied using the MBA with interleaved dispersion bumps.

ACKNOWLEDGEMENTS

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