DESIGN STUDY FOR THE FIRST VERSION OF THE HALS LATTICE

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Abstract

The Hefei Advanced Light Source (HALS) was proposed as a future soft X-ray diffraction-limited storage ring at NSRL. Recently the first version lattice of the HALS storage ring has been studied using a new lattice design concept that we proposed for diffraction-limited storage rings. In this new concept, the beta functions of each cell are made to be locally symmetric. In this paper, an 8BA lattice and a 6BA lattice are designed for the HALS with the first and the second kind of the new concept, respectively. In their nonlinear optimization, good dynamic aperture and momentum aperture can be easily obtained. Especially the dynamic momentum aperture can be larger than 7% or even 10%, which enables long beam lifetime and implementation of longitudinal injection scheme. The studied 6BA lattice is at present considered as the nominal HALS lattice of the first version.

INTRODUCTION

At NSRL, HLS-II, the upgrade of Hefei Light Source (HLS), has been operated for over two years, and significant improvement has been achieved in the performance of the light source. Also, about two years ago, a plan was proposed at NSRL to build a new advanced light source, which was named Hefei Advanced Light Source (HALS). The HALS was hoped to be a soft X-ray diffraction-limited storage ring. At present, the electron beam energy is chosen to be about 2.0 GeV, and the beam emittance is aimed at below 50 pm·rad.

The initial design of the HALS storage ring lattice had been done in the last year, which followed part of the feature of the ESRF upgrade lattice but adopted a 6BA lattice [1]. In each cell of this initial lattice, –I transformation is created for the only two families of sextupoles, which can promise large dynamic aperture (DA). However, the dynamic momentum aperture (MA) is small due to large tune shift with momentum, which will result in very short Touschek lifetime. Then we began to explore new lattice design concept for diffraction-limited storage rings like HALS. Recently we found that, for multi-bend achromat (MBA) lattices, by introducing a local symmetry of beta functions in each cell, –I transformation can be created for many families of sextupoles in the cell so that the lattice flexibility for nonlinear optimization can be much increased. Then some MBA lattices with such a local symmetry were studied for the first version design of the HALS lattice, and the results showed that not only large DA but also large dynamic MA can be easily obtained. At present, a studied 6BA lattice is preferred as the nominal lattice of the first version for the HALS, which has a lower emittance, smaller beta functions and more long straight sections.

LOCALLY SYMMETRIC MBA LATTICES

Generally, for a cell of a synchrotron storage ring lattice, beta functions are symmetric about the midplane of the cell. For the complicated MBA lattices that have been used in diffraction-limited storage ring designs, beta functions can be further made to be locally symmetric about two mirror planes of the cell, which have the same distance from the midplane. If the phase advances between the two mirror planes are made to be

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

where m and n are integers, many nonlinear effects caused by normal sextupoles that are located in the sections with locally symmetric beta functions will be cancelled out in the cell. For convenience, we call such MBA lattices that we proposed above locally symmetric MBA (LS-MBA) lattices, the schematic of which is shown in Fig. 1. According to the position of the midplane of a cell, LS-MBA lattices can be classified into two kinds, as will be described.
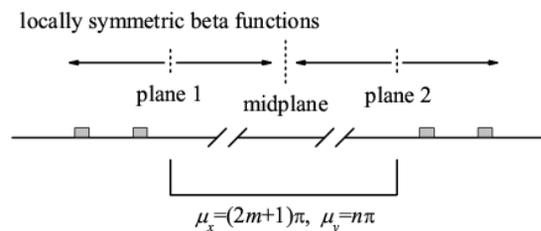

Figure 1: Schematic of a cell of the LS-MBA lattice.

LS-MBA of the First Kind

In the usual representation of a cell, where two halves of the long straight section are at both ends of the cell, the midplane is at the middle of the arc section. The LS-MBA under such a representation is called the LS-MBA of the first kind. Fig. 2 shows a LS-8BA of the first kind, where the upper colour lines represent the locally symmetric beta functions, and the two mirror planes are at the middle between the 2nd and 3rd bending magnets and the 6th and 7th bending magnets.
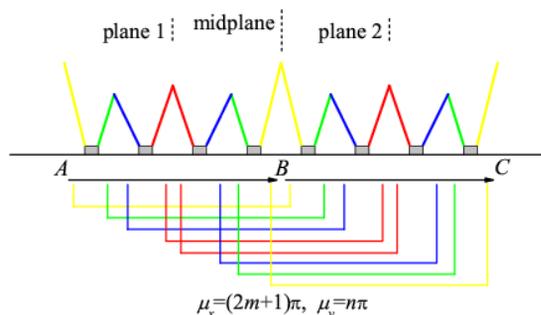

Figure 2: Schematic of a LS-8BA of the first kind.

LS-MBA of the Second Kind

There is an unusual representation of a cell, where two halves of the arc section are at both ends of the cell, the midplane is at the middle of the long straight section. The LS-MBA under such a representation is called the LS-MBA of the second kind. A LS-6BA of the second kind is shown in Fig. 3, and the two mirror planes are at the middle of the 2nd and the 5th bending magnets.
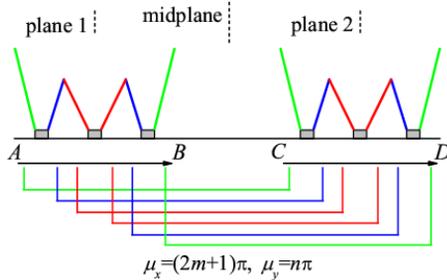

Figure 3: Schematic of a LS-6BA of the second kind.

Note that in the actual design of LS-MBA lattices, there is no need to make local beta functions absolutely symmetric. In addition, the sextupoles located in the sections with locally symmetric beta functions include chromatic sextupoles as well as harmonic sextupoles. The two lattices shown in Fig. 2 and Fig. 3 will be used to design the HALS lattice of the first version.

HALS LATTICE DESIGN

In the first version lattice design, the studied LS-8BA and LS-6BA lattices are denoted as version 1.1 and 1.2.

Version 1.1: LS-8BA Lattice

Following the concept of LS-MBA of the first kind, a LS-8BA lattice was designed for the HALS storage ring. The magnet layout and linear optical functions are shown in Fig. 4, and some main parameters of the ring are listed in Table 1. In the lattice, all bending magnets are combined function ones. To achieve a better local symmetry of beta functions, we have made two changes in the lattice design. First, the triplet in the matching section is changed to a combination of four quadrupoles, i.e., the focusing quadrupole is sliced into two pieces, between which a harmonic sextupole is located. Second, an additional family of defocusing quadrupoles is added adjacent to the 4th and 5th bending magnets. In the lattice design, the phase advances between the two mirror planes are set to 3π and π in the horizontal and vertical directions, respectively. To better satisfy the requirements of LS-MBA, multi-objective particle swarm optimization (MOPSO) algorithm was applied in the linear lattice design, and not only the strengths of magnets but also the positions of magnets and the lengths of bending magnets are the variables to be optimized.

Seven families of sextupoles and one family of octupole, as shown in Fig. 4, are employed for chromaticity correction and nonlinear optimization. MOPSO was also applied in the nonlinear optimization. Now we show two optimized solutions (solution #1 and #2). Fig. 5 shows the frequency map analysis (FMA) for the DA of solution #1, where only

the part of the DA with y below 1.5 mm is present. The tune shift with momentum and off-momentum DAs are shown in Fig. 6, which denote rather good off-momentum dynamics with a large local MA of >7%. Solution #2 is taken as an example to demonstrate the excellent performance of LS-MBA in the nonlinear optimization, especially the off-momentum dynamics. The DA of solution #2 is shown in Fig. 7, which is smaller than that of solution #1 but also larger than 100 rms beam size. While the local dynamic MA of solution #2 can be even larger than 10%, which is shown in Fig. 8, as well as off-momentum DAs.
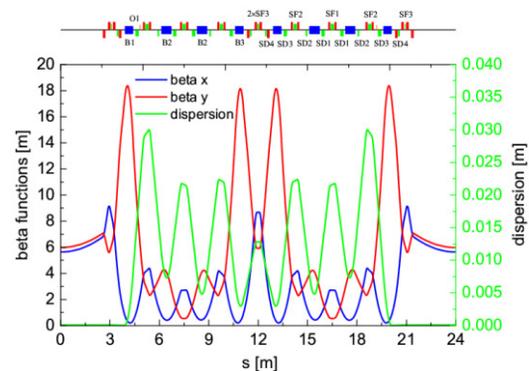

Figure 4: Magnet layout and linear optical functions of the LS-8BA lattice.

Table 1: Main Parameters of the LS-8BA Lattice Ring

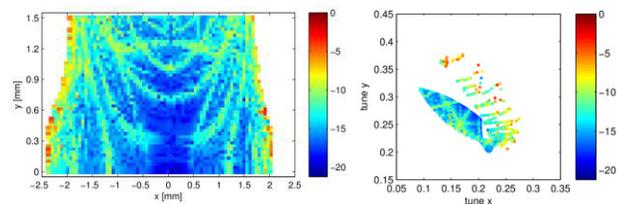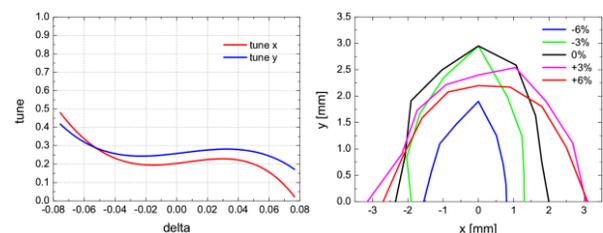| Parameter	Value
Beam energy	2.0 GeV
Circumference	576 m
Number of cells	24
Natural emittance	24.9 pm·rad
Transverse tunes	76.205, 27.258
Natural chromaticities	-136, -116
Momentum compaction factor	5.96×10^{-5}

Figure 5: FMA for the DA of solution #1.

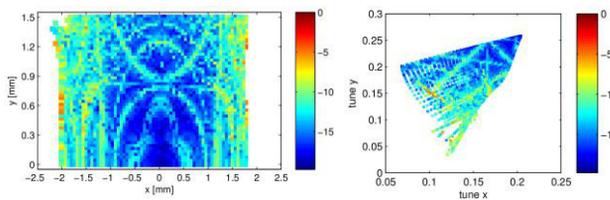Figure 6: Tunes versus momentum deviation (left) and off-momentum DAs (right) [solution #1].

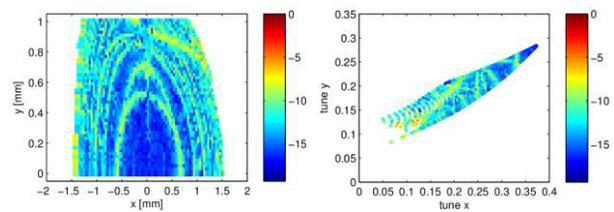Figure 7: FMA for the DA of solution #2.
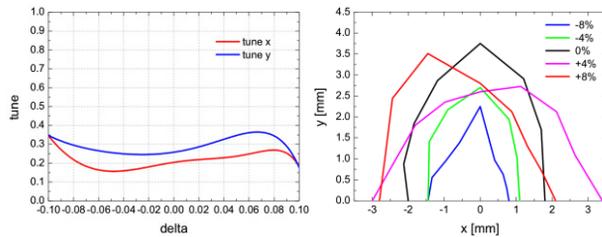

Figure 10: FMA for the optimized DA.

Figure 8: Tunes versus momentum deviation (left) and off-momentum DAs (right) [solution #2].
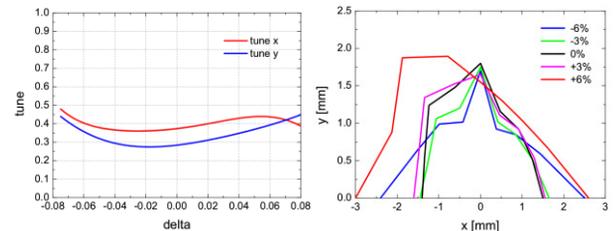

Figure 11: Tunes versus momentum deviation (left) and off-momentum DAs (right).

Version 1.2: LS-6BA Lattice

The concept of LS-MBA of the second kind was also followed by the HALS lattice, and a LS-6BA lattice was designed. The magnet layout and linear optical functions of the lattice are shown in Fig. 9, and some main parameters of the ring are listed in Table 2. In the nonlinear optimization, five families of sextupoles and two families of octupoles are employed as can be seen in Fig. 9. Fig. 10 shows the FMA for the optimized DA with y below 1 mm. The performance of off-momentum dynamics is shown in Fig. 11, from which we can see that the local MA is larger than 7% and the off-momentum DAs do not shrink.
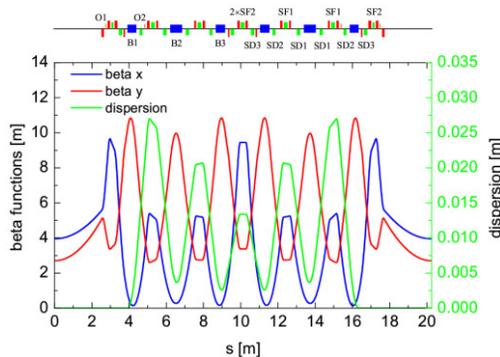
Compared with the LS-8BA lattice, the LS-6BA lattice has a lower emittance, smaller beta functions and more long straight sections for insertion devices. Thus, it was chosen as the nominal HALS lattice of the first version. The excellent on- and off-momentum dynamics will promise long beam lifetime and implementation of longitudinal injection scheme in the HALS.

CONCLUSION

By introducing a local symmetry of beta functions in each cell of MBA lattices, we proposed the concept of LS-MBA lattices, which can be classified into two kinds based on the two representations of a cell. In the LS-MBA lattices, many nonlinear effects can be cancelled out in a cell, and there are many degrees of freedom to minimize tune shifts with amplitude and momentum and high-order resonance driving terms. Two LS-MBA lattices, a LS-8BA of the first kind and a LS-6BA of the second kind, have been applied to the design of the first version lattice for the HALS storage ring, and the nonlinear optimization results are excellent, especially the off-momentum dynamics. The LS-6BA lattice was chosen as the nominal lattice of the first version. In the coming lattice design, longitudinal gradient and reverse bending magnets will be considered to be employed.

Figure 9: Magnet layout and linear optical functions of the LS-6BA lattice.

Table 2: Main Parameters of the LS-6BA Lattice Ring

Parameter	Value
Beam energy	2.0 GeV
Circumference	648 m
Number of cells	32
Natural emittance	18.4 pm·rad
Transverse tunes	88.374, 23.284
Natural chromaticities	-204, -100
Momentum compaction factor	3.42×10^{-5}

REFERENCES

[1] Zheng-He Bai, et al., "Initial Lattice Design for Hefei Advanced Light Source: A VUV and Soft X-ray Diffraction-limited Storage Ring", in Proc. IPAC16, Busan, Korea, 2016.