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SUPER-PERIOD MULTI-BEND ACHROMAT LATTICE WITH INTERLEAVED DISPERSION BUMPS FOR THE HALS STORAGE RING

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Abstract

We have proposed a multi-bend achromat (MBA) lattice concept, called the MBA with interleaved dispersion bumps, in which two pairs of interleaved dispersion bumps are created in each lattice cell. Due to that many nonlinear effects can be effectively cancelled out within one cell and also many knobs can be used for nonlinear optimization, this MBA concept has given both large dynamic aperture (DA) and large dynamic momentum aperture in the lattice design of the Hefei Advanced Light Source (HALS). In this paper, to further enlarge DA, we extend the concept to the case of a super-period lattice consisting of two cells. In the super-period lattice, there are 1.5 pairs of bumps in each cell. A super-period 7BA lattice is preliminarily designed for the HALS, and a larger DA is obtained.

INTRODUCTION

Hefei Advanced Light Source (HALS) [1] brought forward at NSRL is aimed to be a world-class soft X-ray diffraction-limited storage ring (DLSR). The preliminary R&D for HALS was supported by the Chinese Academy of Sciences and local government in the last year. In the recent two years, some multi-bend achromat (MBA) lattices have been studied for the HALS storage ring. A 6BA was first designed for the HALS as the initial lattice [2], which followed the main feature of the hybrid MBA concept proposed by ESRF EBS [3]. Due to very effective nonlinear cancellation within one cell, large dynamic aperture (DA) was achieved. But the dynamic momentum aperture (MA) was small, since it is hard to control momentum dependent tune shifts due to limited knobs (i.e. families of sextupoles) in one cell. To have both good DA and good MA, we considered to develop other MBA concepts, in which not only most of nonlinear effects can be effectively cancelled out within one cell as in the hybrid MBA but also many knobs can be used for nonlinear optimization, including control of momentum dependent tune shift terms.

The first MBA concept that we developed was called locally symmetric MBA (LS-MBA) [4], where beta functions of each cell are made locally symmetric about two mirror planes that are separated by certain transformation. An 8BA and a 6BA with emitances of tens of pm·rad were designed for the HALS as lattices of the first version using LS-MBA of the first and the second kind, respectively. The optimized nonlinear dynamics showed not only large on-momentum DA, but also large enough dynamic MA and large off-momentum DAs. The dynamic MA at long straight sections was larger than 7%. The LS-MBA in [4] has a complicated structure, which we will simplify while having many knobs for nonlinear optimization.

The second MBA concept that we developed was called MBA with interleaved dispersion bumps (IDB-MBA) [5], which was inspired by the hybrid MBA and the LS-MBA of the second kind. In the IDB-MBA, two pairs of dispersion bumps are created in each cell, which are interleaved, like interleaved sextupoles, from the nonlinear cancellation point of view. Using IDB-MBA, two 7BA lattices were designed for the HALS as lattices of the second version [6], one having a lower emittance of 23 pm·rad with longitudinal gradient bends (LGBs) and anti-bends (ABs) employed. With six families of sextupoles used for nonlinear optimization, large on- and off-momentum DAs and large enough dynamic MA were also achieved. The local dynamic MA at long straight sections of the lower-emittance 7BA lattice was even larger than 10%.

Since MA is large enough in the IDB-MBA, we consider to further enlarge DA. The idea is to reduce the number of dispersion bumps while also having many knobs used for nonlinear optimization, which could be realized in a super-period lattice. This paper will give a super-period version of IDB-MBA, and then a super-period 7BA lattice will be preliminarily designed for the HALS.

SUPER-PERIOD MBA LATTICE WITH INTERLEAVED DISPERSION BUMPS

In the hybrid MBA lattice, as shown in the upper plot of Fig. 1, there are one pair of non-interleaved dispersion bumps in each cell, and the phase advances between them satisfy:

$$\mu_x=(2m+1)\pi,\ \mu_y=n\pi, \qquad (1)$$

where m and n are integers, so that most of nonlinear effects caused by the normal sextupoles located in the bumps can be effectively cancelled out within one cell. Note that the sextupoles in the bumps are not interleaved. In the IDB-MBA lattice, there are two pairs of interleaved dispersion bumps, and for each pair of bumps, the phase advances between them also satisfy the relation (1), as shown in the middle plot of Fig. 1. Compared to the hybrid MBA, the IDB-MBA has one additional pair of dispersion bumps, which has both advantages and disadvantages. On one hand, the IDB-MBA can have more families of sextupoles in one cell for nonlinear optimization so that, for example, momentum dependent tune shifts can be better controlled so as to enlarge the dynamic MA. On the other hand, bumps of the IDB-MBA are interleaved and lower, which reduces the effectiveness of the nonlinear cancellation within one cell and thus reduces the DA.

To enlarge the DA of the IDB-MBA lattice, we extend the IDB-MBA to the super-period lattice case, in which the number of dispersion bumps can be reduced. Thus bumps

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will be less interleaved, which could make nonlinear cancellation more effective and thus benefit the improvement of DA. The lower plot of Fig. 1 shows a super-period IDB-MBA lattice, which consists of two cells. We can see that there are three pairs of bumps in a super-cell, or say that there are 1.5 pairs of bumps in each cell. So the bumps in this super-period version of IDB-MBA are less interleaved and higher than those in the basic version of IDB-MBA (the middle plot of Fig. 1), which is of advantage for enlarging DA. And there are also two kinds of bumps in the super-period version as in the basic version, which can also accommodate many families of sextupoles to optimize for example tune shifts with momentum. Note that in the super-period version, the strengths of the three sextupoles in one bump of the red pair can be somewhat different from those in the other bump. Besides, the super-period version can provide more space in the bumps for components. We notice that some DLSRs, such as HEPS [7], Sirius [8], also have super-period lattices.

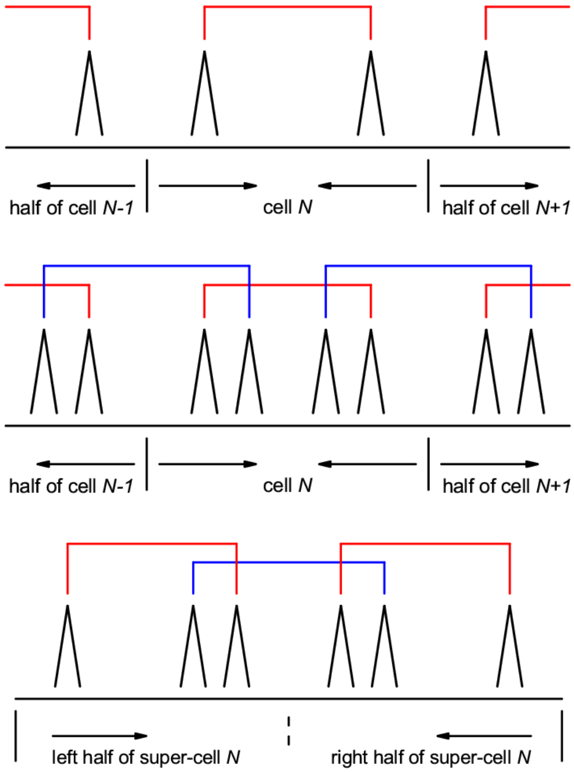

Figure 1: Schematics of the MBA lattice with non-interleaved dispersion bumps (upper), the IDB-MBA lattice (middle) and the super-period IDB-MBA lattice. The phase advances between each pair of dispersion bumps satisfy the relation (1).

DESIGN OF A SUPER-PERIOD 7BA LATTICE FOR HALS

Using the concept of the super-period version of IDB-MBA, a super-period 7BA lattice was preliminarily designed for the HALS storage ring, where the bends are all defocusing combined function ones. The left half of the super-period lattice is shown in Fig. 2, from which we can see that three bumps are created in the half of the super-period lattice and the beta functions in the first and third bumps are almost the same. The first and the third bumps form one pair, and the second bumps of the left half and the right half form another pair. The phase advances between the bumps of each pair are roughly (1.5, 0.5)×2π. The natural emittance of the storage ring is 34 pm·rad, and the main parameters of the storage ring are listed in Table 1. Compared to the 7BA lattice, the version 2.1 of HALS [6], designed using the basic version of IDB-MBA, the bumps of this super-period 7BA lattice are higher and the beta functions in the bumps are more separated, which is beneficial for reducing srengths of sextupoles. Besides, the super-period 7BA lattice provides more space for components in the bumps.

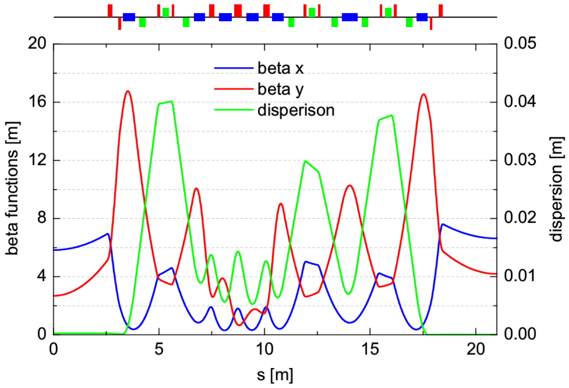

Figure 2: The left half of the super-period 7BA lattice.

Table 1: Main Parameters of the Super-Period 7BA Lattice Storage Ring

Parameter	Value
Energy	2.4 GeV
Circumference	672 m
Number of super-cells	16
Number of long straights	32
Natural emittance	34.0 pm·rad
Transverse tunes	76.337, 27.307
Natural chromaticities	-101, -102
Momentum compaction factor	5.92×10^{-5}
Beta functions at long straights	5.829, 2.679 m 6.627, 4.185 m

Nine families of sextupoles, three in each bump of one half of the super-period lattice, were employed for nonlinear optimization, and the chromaticities were corrected to (4, 3). The three sextupoles in the first bump have somewhat different strengths from those in the third bump to increase the number of knobs, and the DA obtained is larger than that in the case of having the same strengths. The optimized DA, tracked at the long straight with beta functions of 5.829 m and 2.679 m, is shown in Fig. 3, which is larger than that of the 7BA lattice of the version 2.1. The momentum dependent tune changes are shown in Fig. 4, and we can see that the dynamic MA at long straight sections is about 6%, which is, however, smaller than that of the 7BA lattice of the version 2.1, but is also relatively large.

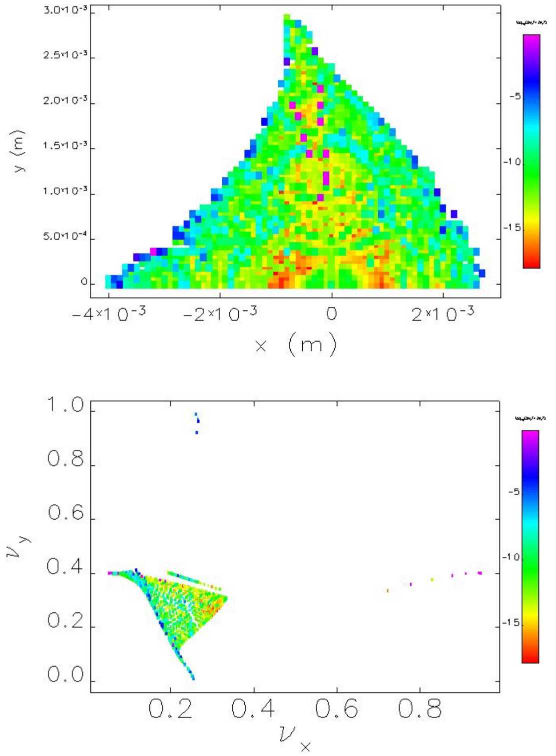

Figure 3: Frequency map analysis for the optimized DA of the super-period 7BA lattice.

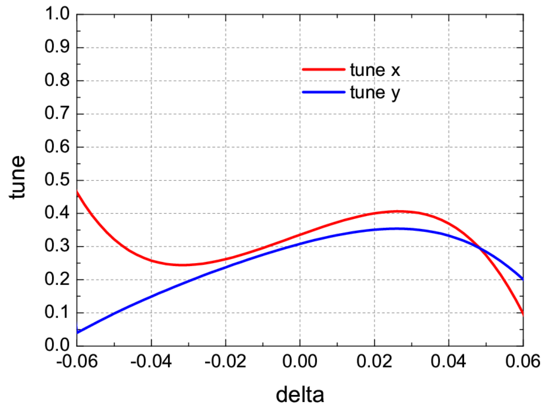

Figure 4: Tunes vs. momentum offset of the super-period 7BA lattice.

We will further optimize the linear lattice and nonlinear dynamics to explore the potential of this super-period 7BA lattice. Besides, we will study the super-period 7BA lattice with some straight sections having low horizontal and vertical beta functions to increase the brightness of insertion devices at these long straight sections as in Sirius [8] and HEPS [7], and we will employ some LGBs and ABs to reduce the emittance of the 7BA lattice of this kind.

CONCLUSION

The IDB-MBA concept was extended to the case of a super-period lattice consisting of two cells, where there are 1.5 pairs of dispersion bumps in each cell. In this super-period version of IDB-MBA, bumps are less interleaved and have higher dispersion values, which could benefit the improvement of DA. Besides, this super-period version can provide more space in the bumps for components. A super-period 7BA lattice was preliminarily designed for the HALS storage ring, and a larger DA was obtained, as well as a large dynamic MA. A more intensive study on the super-period version of IDB-MBA is ongoing.

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