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MULTI-BEND ACHROMAT LATTICE WITH INTERLEAVED DISPERSION BUMPS FOR A DIFFRACTION-LIMITED STORAGE RING

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Abstract

In this paper, we propose a new lattice concept of multi-bend achromat (MBA) for designing a diffraction-limited storage ring, which is inspired by the hybrid MBA concept proposed by ESRF EBS and the locally symmetric MBA concept recently proposed by ourselves. In this new MBA concept, two pairs of dispersion bumps are created in each cell, which accommodate sextupoles to correct chromaticities. For each pair of dispersion bumps, from the point of view of two different representations of a cell, many nonlinear effects caused by itself are cancelled out within one cell. For the two pairs of dispersion bumps, from the nonlinear cancellation point of view, they are interleaved. Compared to the hybrid MBA where only one pair of dispersion bumps is created in each cell, this new MBA can provide more knobs so as to better control tune shift terms, which is especially beneficial for enlarging dynamic momentum aperture.

INTRODUCTION

In the recent two years the MAX IV light source has opened the door to the next-generation synchrotron radiation sources, the so-called diffraction-limited storage rings (DLSRs). Today many advanced light sources are being constructed or designed around the world towards lower emittances than MAX IV, even on the order of tens of pm·rad. Following MAX IV, these DLSRs adopt multi-bend achromat (MBA) lattices to reduce the emittance. Lower emittance generally means stronger nonlinear dynamics. For DLSRs with emittances of about one hundred or tens of pm·rad, the nonlinear dynamics is extremely strong, which is a big challenge for lattice designers.

To combat the very serious nonlinear dynamics in DLSRs with even lower emittances, some MBA lattice concepts with different nonlinear cancellation schemes have been proposed. PEP-X proposed a fourth-order geometric achromat MBA concept, in which the nonlinear cancellation was done over some cells. There are many knobs (i.e. families of nonlinear multipoles) in this concept so that tune shift terms and higher-order resonance driving terms can be well controlled. ESRF EBS proposed a hybrid MBA concept [1], in which the nonlinear cancellation was done within one cell that can be more effective than the cancellation over some cells due to interleaved sextupoles. However, it is hard to control tune shift terms in the hybrid MBA concept due to limited knobs. For the APS-U and HEPS lattices that adopt the hybrid MBA concept but have lower emittances than ESRF EBS, the tune shift with momentum is large and half-integer resonance line will be crossed for particles with relative momentum deviation of about 2~3%.

Recently we proposed a locally symmetric MBA (LS-MBA) concept by making the beta functions locally symmetric about two mirror planes in each cell [2], in which the nonlinear cancellation was done within one cell and also many knobs could be used. The LS-MBA concept was applied to the design of Hefei Advanced Light Source (HALS), and the designed lattices with emittances of tens of pm·rad had excellent on- and off-momentum nonlinear dynamics, especially the dynamic momentum aperture being larger than 7% or even 10%.

In this paper, we develop a new MBA concept following the same philosophy as for the LS-MBA, i.e. doing nonlinear cancellation within one cell and having many knobs to be used. In this new MBA concept, the dispersion in the arc section will have several bumps as in the hybrid MBA so as to reduce the strengths of sextupoles. We will first give a description for this new MBA concept and then apply it to the design of HALS.

MBA LATTICE WITH INTERLEAVED DISPERSION BUMPS

In the hybrid MBA one pair of dispersion bumps is created at both ends of the arc section with a separation of $-I$ transformation, which is very effective for nonlinear cancellation and also can reduce the strengths of sextupoles. However, for each cell there can be placed only three families of sextupoles at most in the dispersion bumps. Due to that two knobs have to be used for correcting horizontal and vertical chromaticities, it is very hard to well control tune shifts with amplitude and momentum simultaneously using the other knobs (including one family of octupole). Our idea is to create an additional pair of dispersion bumps in each cell to increase the number of knobs. However, the problem for this idea is how to make a nonlinear cancellation for the additional pair of bumps. Inspired by the LS-MBA of the second kind that we proposed, the nonlinear cancellation for the additional pair of bumps can also be realized within one cell from the point of view of an unusual representation of a cell.

In the usual representation, we can write a cell as *ABBA*, where *A* represents one half of the long straight section and *B* one half of the arc section. In an unusual representation, we can also write it as *BAAB*. Using these two representations, we have classified the LS-MBA lattices into two kinds. For the hybrid MBA lattice, the nonlinear cancellation between the pair of two dispersion bumps is referred to using the representation of *ABBA*. For a MBA lattice, like the hybrid MBA lattice, with one pair of dispersion bumps satisfying the condition of nonlinear cancellation, if we create a second pair of dispersion bumps, generally the phase advance between the two bumps of the second pair

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will not satisfy the condition of nonlinear cancellation using the representation of *ABBA*. But if using the representation of *BAAB*, the problem of phase advance for the second pair could be solved. Considering the real lattice design, a MBA lattice with interleaved dispersion bumps, as shown in the lower plot of Fig. 1, could realize the nonlinear cancellation within one cell for two pairs of dispersion bumps. In the upper plot of Fig. 1, a MBA lattice with only two dispersion bumps is also shown. From the nonlinear cancellation point of view, the pairs of bumps in the lower plot are interleaved, while the pairs of bumps in the upper plot are non-interleaved. The phase advances for the nonlinear cancellation between one pair of two bumps are

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

for normal sextupoles, where m and n are integers. If n is an odd number, the transformation between one pair of two bumps will be $-I$ transformation. We have found that the MBA lattice with interleaved dispersion bumps can be easily realized based on the hybrid 7BA lattice as will be designed in the next section for HALS.

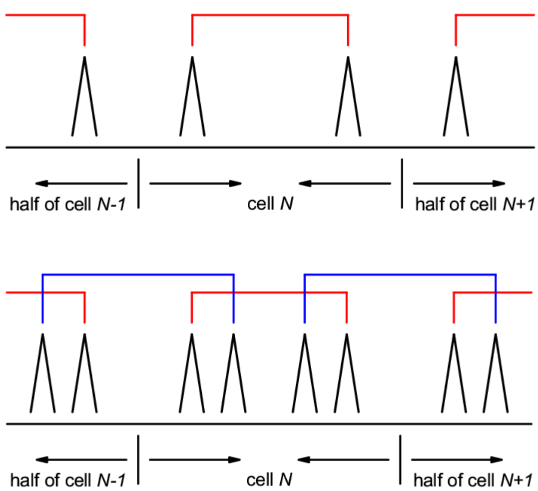

Figure 1: Schematics of MBA lattices with two dispersion bumps (upper) and interleaved dispersion bumps (lower). The nonlinear cancellation is made between each pair of dispersion bumps.

HALS LATTICE DESIGN AND OPTIMIZATION

Now we apply the new MBA concept described above to the design of HALS. HALS is a soft X-ray DLSR proposed by NSRL two years ago, which is being designed aiming at an emittance of tens of pm·rad. An 8BA and a 6BA lattices had been designed for HALS using the LS-MBA concept. Following part of the feature of the hybrid 7BA lattice but using the new MBA concept, a 7BA lattice was recently designed for HALS. The linear magnet layout and linear optical functions are shown in Fig. 2, and some main parameters of the 7BA storage ring are listed in Table 1. In this lattice all bending magnets are combined function ones. From Fig. 2 we can see that four dispersion bumps are created in one cell, which is different from the case in the hybrid 7BA lattice. The 1st and the 4th dispersion bumps in the same cell form the first pair of bumps, and the 2nd bump of the present cell and the 3rd bump of the previous cell form the second pair of bumps. The phase advances between two bumps of the first or the second pair are 3π and π in the horizontal and vertical directions, respectively (i.e. $-I$ transformation). The multi-objective particle swarm optimization (MOPSO) algorithm was applied in the linear lattice optimization, where the magnet layout and strengths are simultaneously optimized to search for the lowest emittance.

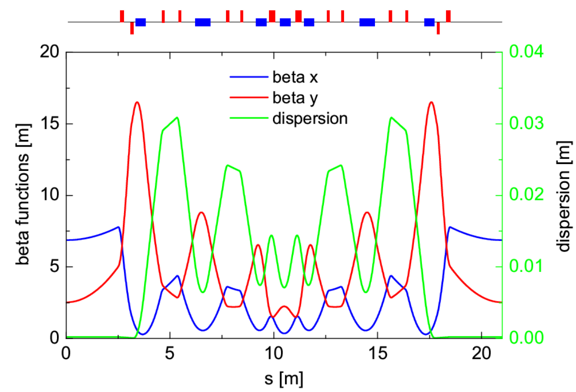

Figure 2: Linear magnet layout and linear optical functions of the HALS 7BA lattice.

Table 1: Main Parameters of the HALS 7BA Lattice Ring

Parameter	Value
Beam energy	2.4 GeV
Circumference	672 m
Number of cells	32
Natural emittance	30.9 pm·rad
Transverse tunes	77.211, 28.281
Natural chromaticities	-105, -103
Momentum compaction factor	6.08×10^{-5}
Length of long straights	5 m
Beta functions at long straights	6.873, 2.526 m

Six families of sextupoles (three families for each pair of bumps) were employed for chromaticity correction and nonlinear dynamics optimization, and no octupole was employed. MOPSO was also applied in the nonlinear optimization. Fig. 3 shows the part of the optimized dynamic aperture (DA) with tunes not crossing the integer resonance line. The tunes and horizontal DAs at different relative momentum deviations are shown in the upper and lower plots of Fig. 4, respectively. From Fig. 3 and Fig. 4 we can see that rather good on- and off-momentum dynamics are achieved, which is beneficial for long beam lifetime and implementation of longitudinal injection scheme in HALS. The maximum strength of sextupoles is in the range of (4000, 4500) T/m^2.

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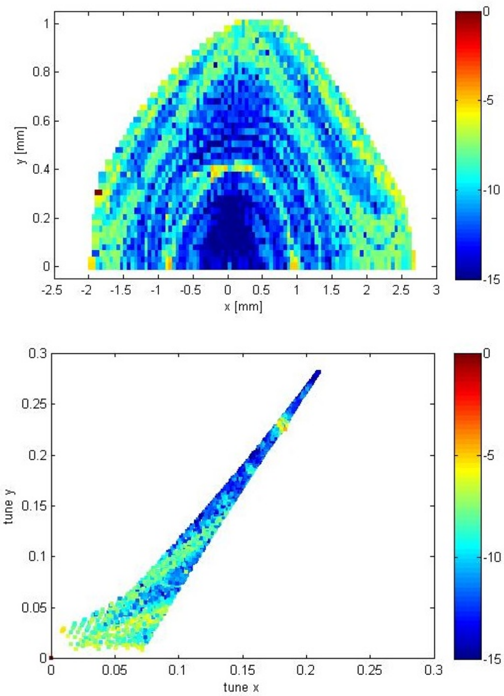

Figure 3: Frequency map analysis for the optimized DA.

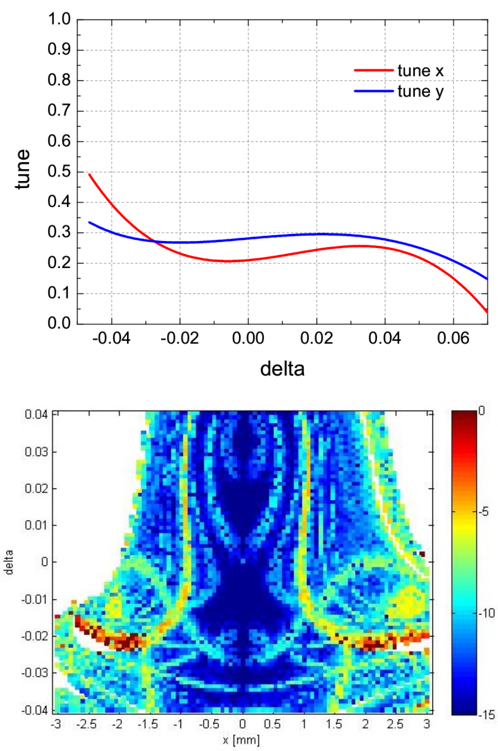

Figure 4: Tunes (upper) and horizontal DAs (lower) versus relative momentum deviations.

CONCLUSION AND OUTLOOK

Inspired by the hybrid MBA and the LS-MBA of the second kind, we developed a new MBA concept, which had two pairs of dispersion bumps in each cell. For each pair of bumps the nonlinear cancellation was done within one cell, and the two pairs of bumps were interleaved from the nonlinear cancellation point of view. Compared to the hybrid MBA, this new MBA can provide more knobs to better control tune shifts with amplitude and momentum. The application of the new MBA concept to the design of HALS showed rather good nonlinear dynamics was achieved, especially the off-momentum nonlinear dynamics.

Besides, following some parameters of HEPS, we also applied the new MBA to the design of a 6.0 GeV DLSR with a circumference of about 1.4 km. A lattice with an emittance of about 50 pm·rad was achieved, and the preliminary nonlinear optimization result showed that the dynamic momentum aperture was larger than 4% without tune crossing half-integer resonance lines. This work will not be reported in this paper. In the coming work, we will consider using octupoles for further nonlinear optimization, and using longitudinal gradient and reverse bending magnets to lower emittance.

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