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SUPER-PERIOD LOCALLY SYMMETRIC LATTICES FOR DESIGNING DIFFRACTION-LIMITED STORAGE RINGS

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Abstract

To achieve better nonlinear dynamics performance for a diffraction-limited storage ring, previously we proposed a locally symmetric multi-bend-achromat (MBA) lattice concept, where beta functions are locally symmetric about two mirror planes of each lattice cell. To have both high-beta long straight sections for beam injection and low-beta ones for higher brightness of insertion device radiation, many storage ring light sources use super-period lattices. The locally symmetric MBA lattice can be naturally extended to the super-period case. In the super-period locally symmetric (SP-LS) lattice, many nonlinear dynamics effects can be effectively cancelled out within one super-period lattice cell, and also there are many knobs to be used for further nonlinear optimization. As examples, two SP-LS lattices have been designed towards diffraction-limited emittances.

INTRODUCTION

Diffraction-limited storage rings (DLSRs) are being developed around the world with multi-bend achromat (MBA) lattices adopted to reduce the electron beam emittance. Longitudinal gradient bends (LGBs) and reverse bends (RBs) can also be employed for further emittance reduction. For a DLSR with an ultra-low emittance, the nonlinear dynamics effects are generally very serious. So effective nonlinear cancellation schemes are usually required to improve the dynamic aperture (DA) and momentum aperture (MA). Both the nonlinear cancellation in the hybrid MBA lattice [1] and that in the SLS-2 lattice [2] are done within one lattice cell, which are generally more effective than the cancellation over some lattice cells. In the lattice design for the HALS [3], a soft X-ray DLSR with a goal of emittance of tens of pm·rad, we have proposed two kinds of MBA lattices with novel nonlinear cancellation schemes, the locally symmetric MBA (LS-MBA) [4] and MBA with interleaved dispersion bumps (IDB-MBA) [5-7]. In these two MBA lattices, not only the nonlinear cancellation is effectively done within one lattice cell, but also many knobs can be reserved for further nonlinear optimization.

To provide both high-beta and low-beta long straight sections for beam injection and higher brightness of insertion device radiation, respectively, super-period lattices have been used in many third-generation light sources and several DLSRs, such as NSLS-II, Sirius and HEPS. We have extended the IDB-MBA lattice to a super-period case [8]. In this paper a super-period locally symmetric (SP-LS) lattice concept will be made from the LS-MBA lattice, and it is a natural extension since the LS-MBA lattice can be treated as a combination of two quasi-period parts. Figure 1 shows the schematic of the LS-MBA lattice concept. In each lattice cell of the LS-MBA, horizontal and vertical beta functions are made locally symmetric about two mirror planes, and the horizontal and vertical phase advances between the two mirror planes satisfy:

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

where m and n are integers. Equation (1) is the condition for cancellation of nonlinear effects induced by normal sextupoles. In this paper, a SP-LS triple-bend achromat (TBA) lattice will be designed for a storage ring with the same energy and circumference as NSLS-II, and a preliminary design of a SP-LS 7BA lattice will also be presented.

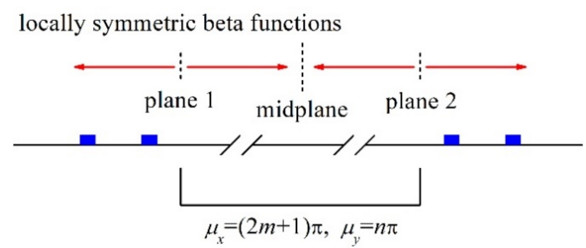

Figure 1: Schematic of the LS-MBA lattice concept.

SP-LS LATTICE

The LS-MBA lattice can be easily extended to a SP-LS lattice consisting of two basic lattice cells, since there are two quasi-period parts in the LS-MBA lattice. Figure 2 shows the schematic of such a SP-LS lattice. Two mirror planes are also the middle planes of the two basic lattice cells with the phase advances satisfying Eq. (1). In the LS-MBA lattice, there is a region with larger beta functions and lower dispersion in the arc section for producing locally symmetric beta functions, which is, however, not good for enlarging DA. While in the SP-LS lattice, such a region is avoid.

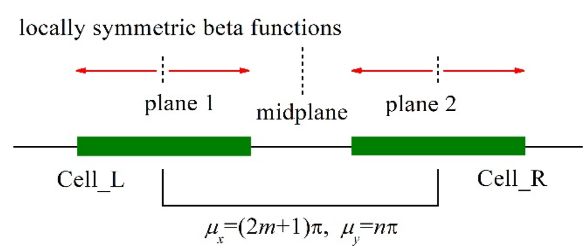

Figure 2: Schematic of a SP-LS lattice, consisting of two basic cells.

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Similar to the LS-MBA, in the SP-LS lattice not only many nonlinear dynamics effects caused by sextupoles can be effectively cancelled out within one super-period lattice cell, but also many families of sextupoes can be employed for further nonlinear optimization. The sextupoles employed can include both chromatic and harmonic ones.

APPLICATIONS

Two lattices will be designed with the SP-LS lattice concept, a SP-LS TBA lattice and a SP-LS 7BA lattice.

A SP-LS TBA Lattice

We have designed a simple SP-LS TBA lattice for a possible upgrade of NSLS-II [9], where the region with locally symmetric beta functions is limited to the arc section. The natural emittance was reduced from 2.1 nm·rad to 0.3 nm·rad in the case of making some changes as small as possible to the current magnet layout of NSLS-II. Now we will extend the locally symmetric region to the dispersion-free matching section for the SP-LS TBA lattice. The lattice is a natural extension of a LS-6BA lattice [4], with the schematic shown in Fig. 3. The designed lattice is shown in Fig. 4. The horizontal and vertical phase advances between the middle planes of the two basic lattice cells are about (3π, π). In either basic cell, the first and last main bends are LGBs, and there are also two RBs combined with horizontally focusing quadrupoles. High-beta long straight sections use a quadrupole doublet, and a triplet for low-beta ones. Some main parameters of the designed storage ring are listed in Table 1, with the same energy, circumference and number of super-period cells as NSLS-2. The natural emittance is 0.295 nm·rad.

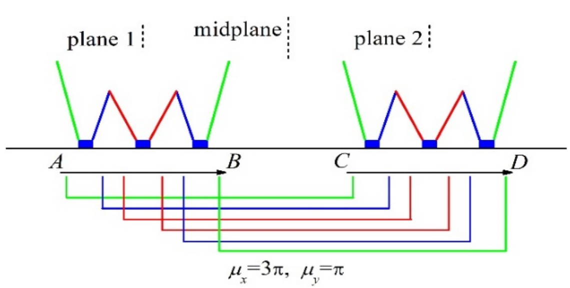

Figure 3: Schematic of a SP-LS TBA lattice. The upper color lines represent locally symmetric beta functions.

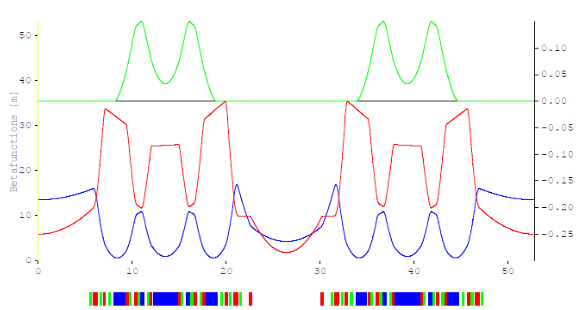

Figure 4: Magnet layout and linear optical functions of a SP-LS TBA lattice. Bends are in blue, quadrupoles in red and sextupoles in green.

Table 1: Main Parameters of the Designed Storage Ring

Parameter	Value
Natural emittance	0.295 nm·rad
Transverse tunes	42.306, 13.254
Natural chromaticities	-81, -70
Momentum compaction factor	1.0×10^{-4}
Damping partition numbers	1.94/1.00/1.06
High beta at long straights	13.494, 5.862 m
Low beta at long straights	4.263, 1.796 m

Three families of chromatic sextupoles and three families of harmonic sextupoles were used for nonlinear optimization, as shown in Fig. 4. In the simple SP-LS TBA lattice [9], main nonlinear effects caused by chromatic sextupoles can be automatically cancelled out within one super-period cell. While in this extended SP-LS TBA lattice, the cancellation can work for all chromatic and harmonic sextupoles. Since two falimies of sextupoles are used to correct chromaticities to the desired values of (2, 2), there are four free knobs used to control higher-order nonlinear effects. The optimized DA, tracked at the middle of high-beta long straight sections, is shown in Fig. 5 with nearly 15 mm in the horizontal direction. The dynamic MA at long straight sections is about 5% as shown in Fig. 6, and Fig. 7 shows off-momentum horizontal DAs.

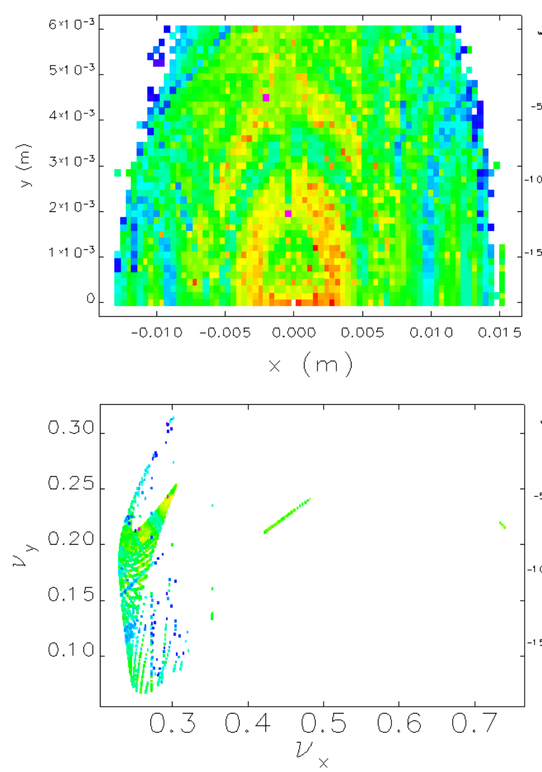

Figure 5: Frequency map analysis of the optimized DA.

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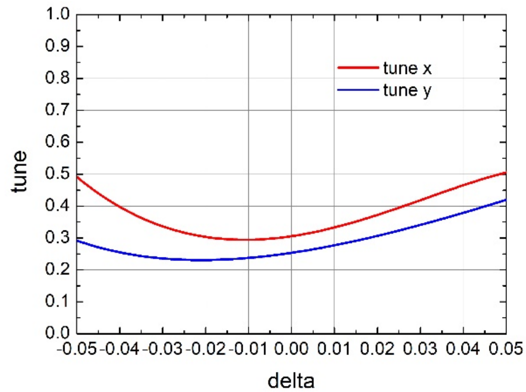

Figure 6: Momentum dependent tune footprints.

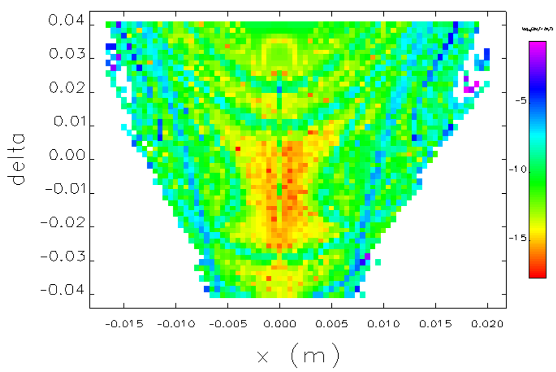

Figure 7: Off-momentum horizontal DAs.

A SP-LS 7BA Lattice

We also made a preliminary design of a SP-LS 7BA lattice for the HALS storage ring. The designed ring was composed of 15 super-period lattice cells with a natural emittance of 47 pm·rad. Figure 8 shows the designed SP-LS 7BA lattice, where all bends are dipole-quadrupole combined function ones. The phase advances between the middle planes of two basic cells are about $(5\pi, 2\pi)$ to cancel the nonlinear effects induced by normal sextupoles. Following the hybrid 7BA lattice, a pair of dispersion bumps are also created in either basic cell with the phase advances of $(3\pi, \pi)$ for very effective nonlinear cancellation. A further study for this lattice is ongoing.

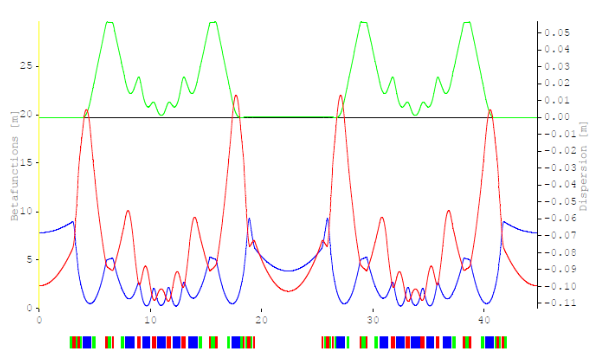

Figure 8: Magnet layout and linear optical functions of a SP-LS 7BA lattice.

CONCLUSION

We have extended the LS-MBA lattice to a SP-LS lattice consisting of two basic cells, in which nonlinear cancellation can be effectively done within one super-period cell with many knobs reserved for further nonlinear optimization. A SP-LS TBA lattice was designed with a natural emittance of 0.295 nm·rad for a storage ring with the same energy and circumference as NSLS-II, and good nonlinear dynamics performance was achieved with six families of chromatic and harmonic sextupoles used. Besides, a preliminary design of a SP-LS 7BA lattice was also made for the HALS storage ring.

ACKNOWLEDGEMENTS

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