INITIAL LATTICE DESIGN FOR HEFEI ADVANCED LIGHT SOURCE: A VUV AND SOFT X-RAY DIFFRACTION-LIMITED STORAGE RING

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Abstract

The upgrade project of Hefei Light Source was successfully completed in 2014 and has been operated for synchrotron radiation users since 2015, which is a second generation light source in the range of VUV and soft X-ray at NSRL in China. To meet the future requirements for users, more efforts are now putting at NSRL into the design of Hefei Advanced Light Source (HALS), a new VUV and soft-X ray diffraction-limited storage ring. The HALS storage ring will have an energy of 2 GeV and a natural emittance of about 50 pm·rad. This paper reports the initial lattice design studies, including linear optics design and nonlinear dynamics optimization.

INTRODUCTION

The Hefei Light Source (HLS) at NSRL located on the west campus of USTC is the first dedicated synchrotron radiation facility in China built in 1980s as a VUV and soft X-ray source. In recent years, a major upgrade to HLS [1] had been successfully carried out. The storage ring was reconstructed with DBA structure instead of the previous TBA while still maintaining the same circumference and cell number as before. After the upgrade, the natural emittance of HLS was reduced from 166 nm·rad to less than 40 nm·rad due to the use of strong focusing quadrupoles, thus providing higher brightness light for synchrotron radiation users. The number of insertion device straights was increased from 2 to 6, and five insertion devices had been installed. In addition, the linac energy was raised to implement full energy injection.

Now NSRL is putting one part of its efforts into continuously improving the performance of HLS, which includes increasing beam current, further lowering beam emittance and conducting top-up injection scheme. Another major effort is putting into the design of a green-field synchrotron source, the Hefei Advanced Light Source (HALS), to satisfy the future requirements. The HALS will be a diffraction-limited storage ring in the radiation range of VUV and Soft X-ray. The beam energy is 2 GeV, and the beam emittance is aimed at about 50 pm·rad. Our initial lattice study showed that a circumference within 400 meters is a better balance between the goal of beam emittance and the cost of project. Though some related design work had been done years ago [2], an intensive study has just begun for HALS. In addition to physical design, some studies on related technology for HALS are also on the way.

HALS STORAGE RING LATTICE DESIGN

As some designs of light sources towards diffraction-limited storage rings, the HALS storage ring also adopts MBA structure and employs combined bending magnets to lower beam emittance.

Linear Lattice Design

To achieve the goal of a beam emittance of about 50 pm·rad, a ring composed of a number of identical TME-like units with combined bending magnets is numerically studied by scanning magnet strengths in reasonable ranges. It was found that the number of bending magnets required is about 140 in our consideration. So two kinds of lattices, 20 × 7BA and 24 × 6BA, have been studied for HALS storage ring. But we put more effort on the 6BA structure in our present case where no longitudinal gradient bending magnet is employed, because 6BA can provide better phase advances between sextupoles in our case.

Our 6BA lattice design followed part of the feature of the ESRF upgrade lattice [3], but some modifications were made. Except for the use of longitudinal gradient bending magnets, the main feature of the ESRF upgrade lattice is that two large dispersion bumps are made at the two ends of the arc in each cell to efficiently compensate for chromaticities and the chromatic sextupoles located in these two bumps are separated by –I transformation to cancel most of undesirable nonlinear effects, thus promising good nonlinear dynamics. For ESRF upgrade lattice, the phases vary very slowly in the bumps due to large beta functions. So in each cell the phase advances between each sextupole in one bump and its mirror sextupole in the other bump can produce an approximate –I transformation. However, for more general cases where at least one beta function is very small at somewhere in the bump, not each sextupole and its mirror sextupole can have an approximate –I transformation, which may not yield as good nonlinear dynamics as in the ESRF case.

To use the concept of –I transformation between two created bumps, our HALS lattice have been designed based on a locally symmetric configuration, which is schematically shown in Figure 1. In each cell, the horizontal and vertical beta functions from the exit of the first bending magnet to the entrance of the second bending magnet are symmetric with respect to the midplane between these two bending magnets. Suppose the longitudinal distance between the first bending magnet and the second last bending magnet is L; then for any point in the first bump with longitudinal coordinate z and its corresponding point in the second bump with coordinate

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$L+z$, the phase advance between them is a constant number. So we can set the phase advance to produce –I transformation. Then, for example, the combination of two defocusing sextupoles with the same integral strength, which are located close to the first bending magnet and the last second bending magnet, respectively, as shown in the lower plot of Figure 1, can eliminate many undesirable effects produced by themselves.

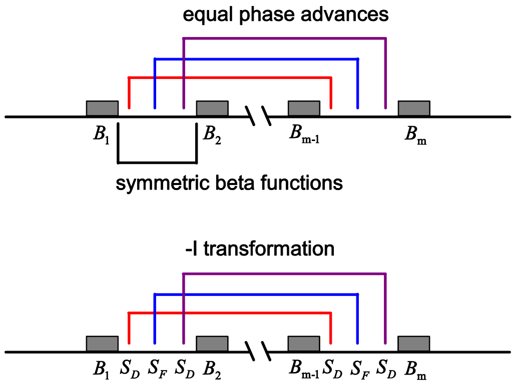

Figure 1: Local symmetry in an *m*BA lattice cell.

This locally symmetric lattice configuration has some advantages. First, in the ideal case with perfect local symmetry and exact –I transformation, a third-order geometric achromat can be created in each cell by two families of symmetrically distributed sextupoles as shown in the lower plot of Figure 1. Second, –I transformation can be universally valid, especially for the typical case where at the location of focusing sextupoles the vertical beta function is very small and at the location of defocusing sextupoles the horizontal beta function is very small. Furthermore, due to the independence of –I transformation on such beta functions in bumps, this lattice configuration can release more tune space for working point choice. To increase more variables of sextupoles for better nonlinear optimization, we can group two cells with, for example, four families of sextupoles like in ESRF case. In the real world, the local symmetry can be slightly broken to choose better working points.

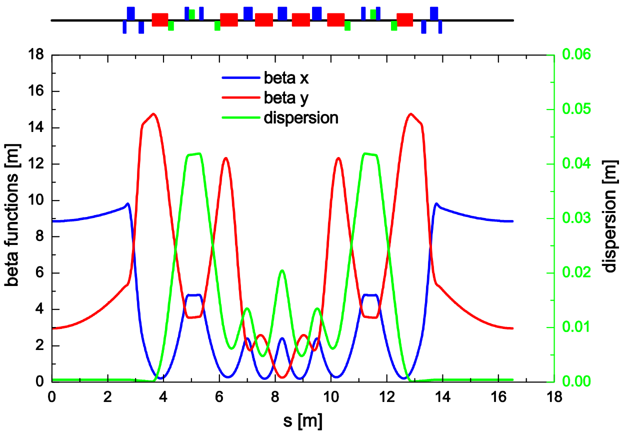

Figure 2: Linear optical functions and magnet layout of one cell of HALS storage ring.

Table 1: Main parameters of HALS storage ring

Parameter	Value
Beam energy	2 GeV
Circumference	396 m
Lattice structure	24×6BA
Natural emittance	47 pm·rad
Transverse tunes	58.145, 20.199
Natural chromaticities	-108, -89
Momentum compaction factor	9.8×10^{-5}
Energy spread	5.4×10^{-4}

Following the above locally symmetric configuration, we have initially designed a 6BA lattice for the HALS storage ring using MOPSO algorithm. In general, MOPSO converges faster than MOGA, and we have used it for some lattice designs and optimizations [4, 5]. A candidate lattice was selected with a natural emittance of 47 pm·rad. Figure 2 shows its linear optical functions and magnet layout of one cell. The main parameters of the storage ring are shown in Table 1. Considering the chosen transverse tune region, the local symmetry in bumps is somewhat broken and –I transformation is not strictly satisfied. Besides, focusing sextupoles are not placed at the center of the bump but with some deviation to leave some space for octupoles. For this lattice, the horizontal phase advance in the bump is not very small due to small horizontal beta function, especially at the location close to bending magnets where defocusing sextupoles are placed, so the locally symmetric configuration can work to produce an approximate –I transformation between sextupoles.

In our linear lattice optimization, an overall optimization had been done using MOPSO algorithm, in which the decision variables include not only the strengths of quadrupoles but also the lengths of bending magnets and the lengths of drifts. After the optimization, optimal solutions were obtained with lower natural emittance, larger momentum compaction factor and lower magnet strength compared with the case where only the strengths of quadrupoles are decision variables. The natural emittance is even lowered by about 20 percent. The maximum strength of quadrupoles is about 79 T/m, and the maximum quadrupole component of combined bending magnets is about 27 T/m. Besides, the lengths of three families of bending magnets are not equal, but have small differences.

Nonlinear Dynamics Optimization

At the present stage of nonlinear dynamics optimization, we used the program OPA and employed only two families of chromatic sextupoles to preliminarily study the nonlinear dynamics. For the lattice above, the nonlinear dynamics results are shown in Figure 3 and Figure 4, which show the horizontal dynamic apertures and transverse tunes at different momentum offsets, respectively. We can see that large dynamic aperture is achieved, but that the horizontal tune shift with momentum is large.

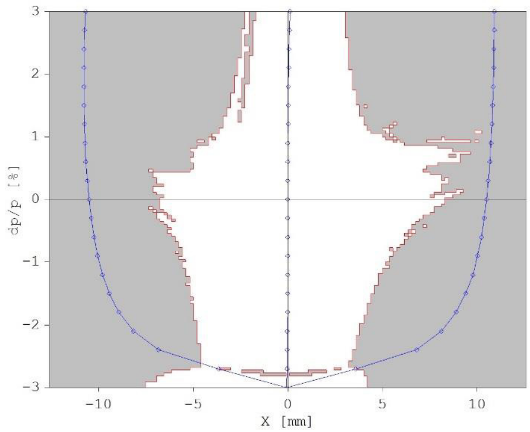

Figure 3: Horizontal dynamic aperture vs. momentum offset (with two families of sextupoles).

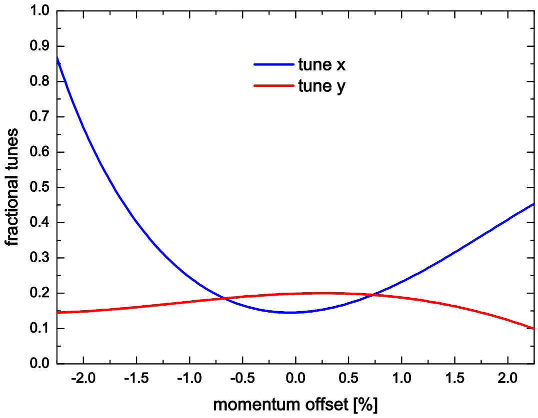

Figure 4: Fractional tunes vs. momentum offset (with two families of sextupoles).

A comprehensive and intensive nonlinear optimization will be done with more families of chromatic sextupoles and the addition of octupoles using MOPSO. Amplitude dependent tune shift and energy dependent tune shift will be carefully treated to obtain better dynamic aperture and momentum aperture with errors. The choice of working point will be also carefully treated. Some other lattice solutions with rather different transverse tune regions and other properties will be studied to provide alternative lattice solutions.

The effects of IBS and other collective effects, injection scheme and by-pass FEL are being studied. Some other lattice structures that may include non-conventional bending magnets will be also studied for HALS storage ring.

CONCLUSION

At NSRL, a VUV and soft X-ray diffraction-limited storage ring, named HALS, is being designed aiming at a beam emittance of about 50 pm·rad at 2 GeV. We have initially studied a 6BA structure lattice for the HALS storage ring based on a locally symmetric cell configuration where beta functions between some bending magnets are symmetric. The preliminary nonlinear dynamics results showed that the 6BA structure is a good option for the HALS storage ring lattice. More intensive nonlinear dynamics optimization will be studied in the coming time, as well as other lattice solutions with different transverse tunes and other properties.

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