THE LATTICE DESIGN OF HEFEI ADVANCED LIGHT SOURCE (HALS) STORAGE RING*

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Abstract

The purpose of HALS (Hefei Advanced Light Source) is to provide synchrotron radiation with high brilliance and better coherence in the VUV and soft X-ray range to synchrotron radiation users. To enhance brilliance and coherence, very low beam emittance is required. The emittance design goal of HALS is lower than 0.2nm.rad, corresponding to full lateral transverse coherent above 2.4nm wavelength. Considering the dependence of undulator radiation spectrum on beam energy and achievable strength parameters of undulator, the beam energy of storage ring is set to 1.5 GeV. To lower beam emittance, not only more dipoles are needed, also stronger focusing. At same time, strong chromatic sextupoles are necessary to compensate large natural chromaticity and result in that storage ring becomes strong nonlinear. Under the limitation of storage ring circumference, possible focusing structures for HALS were studied. Linear optics and nonlinear optimization of HALS were briefly introduced in this paper. And the effect of insertion device on dynamic aperture and compensation scheme were discussed preliminarily.

INTRODUCTION

HLS (Hefei Light Source) is a dedicated second generation light source, spectrally strongest in VUV and soft X-ray range. With the increasing demand from synchrotron radiation users and development of third generation light source, the capability and performance HLS is lag behind and can not meet the requirements of advanced synchrotron radiation activities. To enhance competition of NSRL (National Synchrotron Radiation Laboratory), a scheme of new VUV and soft X-ray light source was brought forward, which is named Hefei Advanced Light Source. Considering various factors, storage ring based conventional synchrotron radiation research facility was adopted [1]. In the following sections, detail of lattice design of HALS storage ring was introduced briefly.

DESIGN GOAL

Firstly, we hope that the new light source was located in current campus of NSRL. Due to limitation of available space for campus, the circumference or diameter of storage ring was limited to 130m. Then, the capability and performance of HALS should be comparable with advanced VUV and soft X-ray light source in the world. For enhancement of brilliance and coherence of HALS in the soft X-ray range, the design goal of beam emittance is lower than 0.2nm.rad, corresponding to diffraction limited beam emittance at 493eV. As general consideration of light source, the insertion devices should be main radiation sources, thus the number of straight section for insertion device should be as more as possible and their length should be long. The baseline of HALS requires that number of insertion devices is more than 12 and their length is longer than 5m.

LINEAR LATTICE CONSIDERATION

To achieve such low beam emittance, two design strategies can be employed. The first method is adoption of stronger focusing to lower the emittance of bare lattice, as the design of third generation light source. The second is decreasing beam emittance with the help of damping wiggler, such as NSLS-II and PETRA-III physical design.

Above all, we must determine the focusing structure of bare lattice. The dependence of beam emittance on main parameters is

$$\varepsilon_{x0}\left[nm\cdot rad\right]=1470\frac{\left(E\left[GeV\right]\right)^2}{J_x}\frac{F_1F_2\theta^3}{12\sqrt{15}} \quad (1),$$

where factor F_1 accounts for different focusing type, factor F_2 is dependent on detail lattice design and reflects the distance to theoretical emittance limit of a lattice, θ is deflecting angle of dipole. The beam energy is 1.5 GeV, which is beneficial to low emittance due to the square dependence and production of long wavelength synchrotron radiation from undulators. Except for stronger focusing strength, more dipole is necessary to ultra-low emittance lattice. Also, increasing horizontal damping partition number is helpful to decrease emittance, which needs utilization of quadrupole-dipole combined function magnets. In physical design of recent third generation light source, the factor F_1 reflecting focusing strength is above 2 normally. Under the circumference limitation, DBA (Double Bend Acromat), TBA (Triple Bend Acromat), QBA (Quadruple Bend Acromat), FBA (Five Bend Acromat), SBA (Six Bend Acromat) and SBA (Seven Bend Acromat) were calculated. For different focusing structure, the factors F_2 reflecting the theoretical emittance limit of a cell, are different and were listed in table 1 [2]. To relax synchro-betatron coupling effects and effects of insertion device on emittance growth, the design strategy of dispersion free straight

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section in HALS were decided. The different design and achieved beam emittance of various focusing structure are listed in table 1. The number of dipoles in DBA and TBA is less than that of others and about 60 due to circumference limitation. So achieved emittance of these two lattices is larger than that of others and about 0.8nm.rad. To achieve the emittance goal, more damping wiggler is needed. At other side, the available straight lines are also more. The number of dipoles in QBA, FBA, SBA and SBA is more than 80 and the achieved emittance of bare lattice is lower and the damping wiggler needed is less or unnecessary. Considering the achieved emittance and number and length of straight line, FBA with 18 super-periods was chosen for HALS. Its emittance of bare lattice is 0.28nm.rad, several damping wigglers are needed to lower beam emittance and fight with intra beam scattering effects. The figure 1 showed the β and dispersion functions of one cell. The figure 2 is the beam size along one cell assuming the betatron coupling is 10% and emittance is 0.2nm·rad.

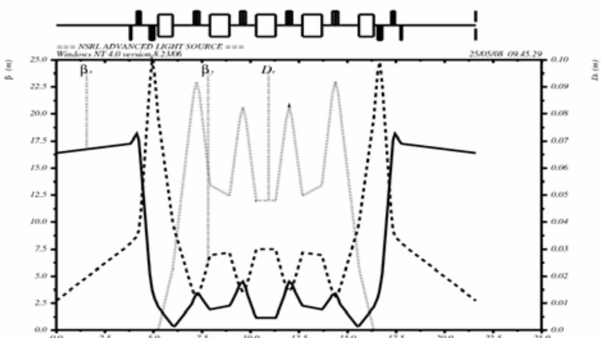

Figure 1: β and dispersion functions of one cell.

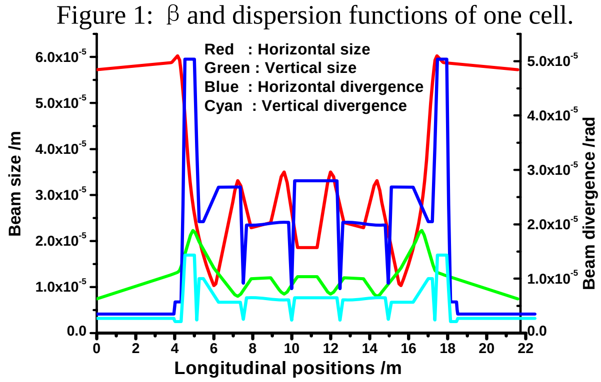

Figure 2: Beam sizes and divergence angles of one cell.

Table 1: Study results for different focusing structure

	F_2	N_{dip}	$\varepsilon_{achieved}$	N_{ID}	$L_{ID,total}$
DBA	3	64	~0.70nm.rad	32	196.0m
TBA	2.326	60	~0.75nm.rad	20	160.0m
QBA	2.0	80	~0.34nm.rad	20	152.0m
FBA	1.796	90	~0.28nm.rad	18	140.4m
SBA	1.667	96	~0.22nm.rad	16	121.6m
SBA	1.571	98	<0.2nm·rad	14	106.4m

NONLINEAR DYNAMICS

Due to ultra low emittance of HALS storage ring, the natural chromaticity is large. Together with the small dispersion function in arcs, the sextupole strengths to compensate natural chromaticity are very large and introduced strong nonlinear effects, which limit dynamic aperture and transverse momentum aperture severely. With the help of BETA [3], OPA [4] and MAD [5] programs, nonlinear optimization of storage ring were studied. For different linear optics parameters, except for chromaticity-compensation sextupoles, several families of harmonic sextupoles were introduced. Then OPA and BETA codes were used to optimizing of nonlinear dynamics. In the optimization of OPA, the objected values and weight values of third and fourth resonance driving terms, second order chromaticities and tune shifts with amplitude are tested and determined according particle tracking results [6]. In the optimization of BETA, step-by-step chromaticity compensation procedure was adopted [7]. The final optimization results of dynamic aperture using above codes are similar. We have found that depending on nonlinear optimization of sextupole compensation scheme only is not enough to enlarge dynamic aperture due to strong nonlinear effects or insufficiency of optimization procedure. Then, we resort to help of linear optics optimization. Careful linear optics matching, especially betatron phase advances between chromatic sextupoles is necessary and important. The figure 3 showed the 2000-turn dynamic aperture of on-momentum and off-momentum particles at the middle of straight section, whose physical aperture is 10×4mm. The transverse momentum aperture was calculated according to following formula [8],

$$\delta_{E,\max}\left(s_0\right)=\min_{s\in[0,L]}\left|\frac{A_{apr,x}\left(s\right)}{\left|\eta_x\left(s\right)\right|+\sqrt{H_x\left(s_0\right)\beta_x\left(s\right)}}\right| \quad (2),$$

where $A_{apr,x}$ is horizontal physical aperture, $H_x\left(s_0\right)$ is Courant-Snyder invariant at s_0. Rough estimation of transverse momentum aperture is $\left(+3.30,-5.50\right)$, larger than RF momentum aperture. The main parameters of HALS storage ring were listed in table 2.

Table 2: Main parameters of HALS storage ring

Quantities	Values
Circumference (m)	388
Energy (GeV)	1.5
Focusing type	Combined FBA
Super-period number	18
Length of straight section (m)	7.6
Emittance of bare lattice (nm·rad)	0.28

Emittance with DW (nm·rad)	<0.20
Transverse tunes	29.32/10.29
Natural chromaticities	-55/-51
Momentum compaction factor	0.00047
Energy spread	0.00022
Revolution frequency (MHz)	0.7710
Harmonic number	648
Damping times (ms)	64/112/90
Damping partition numbers	1.76/1.0/1.24
Energy loss without ID (keV)	34

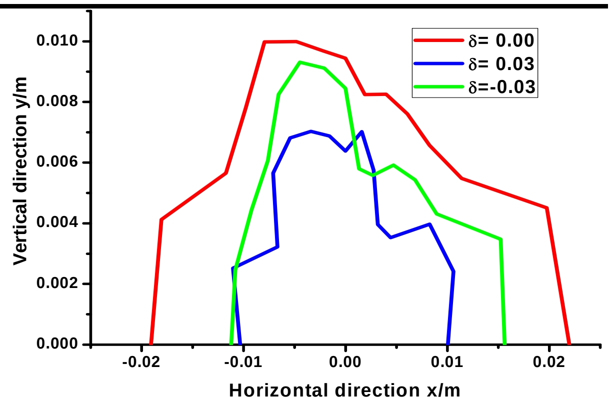

Figure 3: 2000-turns DA at the middle of straight section.

INSERTION DEVICE COMPENSATION

The insertion devices would be main light source of HALS. Except for damping wiggler controlling beam emittance and damping time, various insertion devices are needed for synchrotron radiation users. For example, short period superconducting undulator, in-vacuum pure permanent undulator, cryogenic undulator, elliptical or helical undulator, superconducting wiggler, etc. Without detail of insertion device design, we have only discussed effects of several planar insertion devices on linear optics and dynamic aperture, including short period undulator to produce high brilliant soft X-ray, long period undulator to produce long wavelength radiation and damping wiggler. The triplet was installed at straight section and compensation of linear optics distortion and tune shifts coming from insertion devices is easy made. With appropriate compensation scheme, their effects on dynamic aperture can be alleviated largely. The dynamic aperture with one type insertion devices is showed in figure 4. Although dynamic aperture was shrunk, but still larger than aperture of vacuum chamber, which is 10mm in horizontal and 4mm in vertical plane.

INJECTION BUMP SYSTEM

Local bump method was adopted to accomplish beam injection of HALS. Four kicker magnets were located at one straight section to produce local bump. The height of local bump is about 10 mm and the strength of each kicker is about 6.7mrad. The results of injected beam and stored beam tracking study of injection process are not presented here in detail. According to injection tracking, the emittance of injected beam should be small for high injection efficiency.

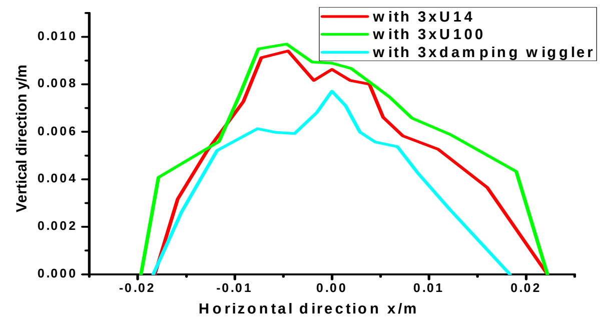

Figure 4: 2000-turns DA with 3 type insertion devices.

DISCUSSION AND CONCLUSION

At current stage, the lattice design and nonlinear optimization of HALS was made. In principle, there are no unconquerable obstacles to achieve the target beam emittance at designed beam energy. Of cause, many works, such as effects of various insertion devices, error effects and correction, stabilization of orbit, etc, are needed study dedicatedly in the later. And further optimization of linear optics and nonlinear optimization is also necessary and would be enhanced in the near future. We hope intensify the cooperation with all friends interested in HALS and make the performance of HALS better.

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