A LOW EMITTANCE LATTICE DESIGN FOR HLS STORAGE RING*

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Abstract

Reducing beam emittance is the most effective measure to enhance brilliance of light source. HLS (Hefei Light Source) is a second generation synchrotron light source, whose emittance is relatively large. To improve the performance of HLS, a new low emittance lattice, whose circumference is similar to that of current storage ring but the focusing structure was different, was studied and presented in this paper. The new ring can be set upon current ground settlement of HLS, while all magnets would be reconstructed. The new designed lattice has two operation modes, the low emittance mode, whose purpose is to reduce beam emittance and to increase the number of straight section, and the low momentum compaction mode, whose purpose is to adjust bunch length for the production of coherent THz radiation. After optimization, beam emittance was reduced to several nm•rad, and the dynamic aperture for on-momentum and off-momentum particle is large enough. It is conceivable that, with the new lattice, the brilliance of HLS should be increased two orders.

INTRODUCTION

HLS (Hefei Light Source) is a dedicated synchrotron radiation research facility, spectrally strongest in VUV and soft X-ray, designed and constructed in 1980's, accepted to regular service in 1991[1]. From 1999 to end of 2004, its Phase II Upgrade Project was carried out, whose main purpose is to improve reliability and performance of HLS and to enhance the research efficiency [2]. Table 1 gives the main parameters of HLS storage ring. Figure 1 gives the brilliance curves of HLS, where the brilliance of dipole radiation and superconducting wavelength shifter radiation is about 10^{12}, while the undulator radiation is about 10^{15}~10^{16}.

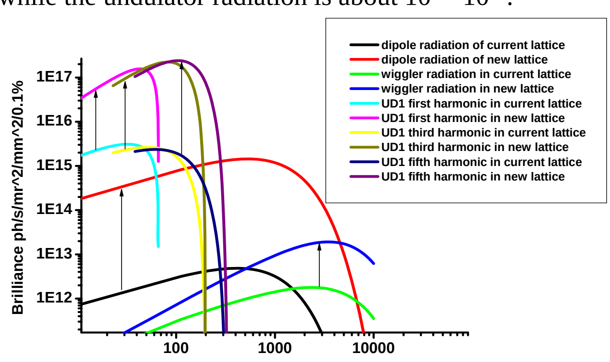

Figure 1: Brilliance of current HLS and new lattice

Table 1: Main parameters of HLS

Injection / operation energy	200 / 800MeV
Circumference	~66m
Focusing type	4×TBA
RF frequency	~204MHz
Emittance	151/15nm•rad
Transverse tunes	3.54 / 2.60
Momentum compaction factor	0.0444
Operation beam intensity	~250mA
Radiation loss per turn	16.3keV
Straight section	4×3.3m
Field of dipole	1.2T
Critical wavelength of dipole radiation	2.4nm

There are two reasons for the unsatisfactory brilliance of HLS. First, the number of straight section for insertion device is limited. There are four straight sections, the first was used for injection system, and the second was used for RF cavity and single period superconducting wavelength shifter, the third and last can be used for undulators. Now most synchrotron radiation beamlines and endsations used the dipole radiation. Another reason is relatively large beam emittance. Some attempts were made to reduce beam emittance in these years. Unfortunately, the experimental results are not comfortable for some reasons [3]. There seem exist some disadvantages of current focusing structure. For example, its minimum beam emittance is about ten nm•rad, it is impossible to reduce beam emittance much; and when beam emittance is very low, the beta functions are not satisfying and results in the sensitivity to various errors [4]. Of cause, the number of straight section limits the usage of insertion device. So, it is more rational to adopt new focusing structure, whose beam emittance is smaller and number of straight section is more. Before, a lattice with 6 super periods was studied [5] and displayed good linear and nonlinear properties. In this paper, a lattice with 8 super periods was presented. Compared with old design, the structure is more compact, while the emittance was reduced to 4 nm•rad.

FOCUSING STRUCTURE

To achieve the purpose of reducing beam emittance and increasing of insertion device number, the DBA (Double Bend Achromat) is the best candidate of focusing structure. In order to installation of current undulator, the length of straight section is larger than 3.2m. For upgrade

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storage ring at current ground settlement, the circumference of ring is about 66m. The length of one super period is about 8m. The limited circumference brought some difficulty to the magnet layout. To release space requirement, the magnet with integrated quadrupole and sextupole components was used in the lattice design. According to experiences of UVSOR [6] and other light source, the property of combined quadrupole and sextupole magnet is acceptable. The minimum emittance of DBA can be easily estimated from formula:

$$\varepsilon_{\min} = C_q \gamma^2 \theta_{dipole}^2 \big/ 4\sqrt{15} J_x \quad (1)$$

where $C_q = 3.83\times10^{-13}$, γ is relativistic factor, J_x is horizontal damping partition number, θ_{dipole} is defecting angle of dipole. If the dispersion function at straight section is not zero, the emittance can be reduced to $\varepsilon_{\min}/3$. The magnet layout is showed in figure 2. To improve the flexibility of lattice, 5 quadrupoles were used per super period. The integrated sextupole component of quadrupole at arc can be used to correct natural chromaticity, and the integrated sextupole component of quadrupole at straight section can be used to enlarge dynamic aperture.

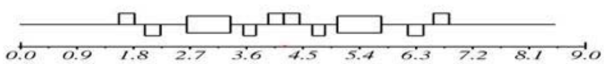

Figure 2: layout of one cell

LOW EMITTANCE MODE

There are many codes for storage ring design, for example, MAD-X, TRACY-II, BETA, AT based on MATLAB, ELEGANT, etc. The MAD-X [7] was used in the linear optics matching. First, an achromatic mode was studied. The beam emittance is about 7 nm•rad. Maximum beta function is similar to that of current operation mode. The figure 3 gives the beta and dispersion function of one period. Than, the OPA [8] software was used to optimize the nonlinear beam dynamics. To obtain large dynamic aperture, the weight values of various resonance drive terms in OPA are important. The figure 4 gives 2000 turn's dynamic aperture for on-momentum and off-momentum aperture at the middle of straight section, which was calculated by ELEGANT [9]. To verify the nonlinear properties of lattice, multiple field errors were included in particle tracking. The horizontal dynamic aperture is larger than 30 mm, and the vertical dynamic aperture is larger than 25 mm.

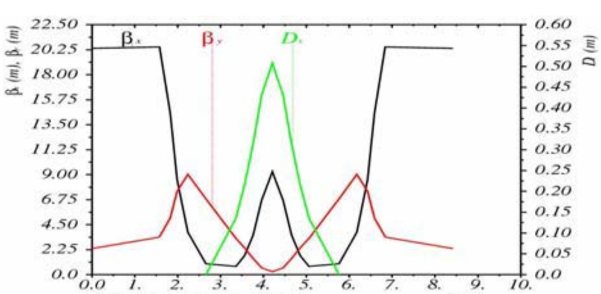

Figure 3: Beta and dispersion functions of one cell

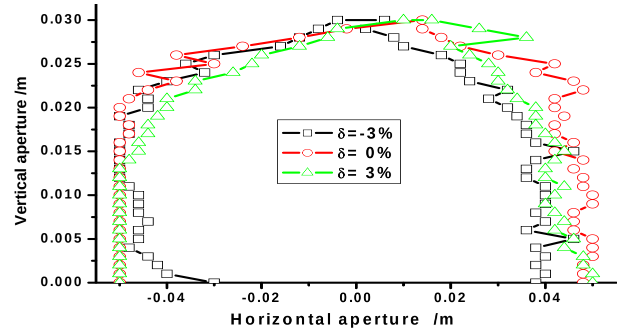

Figure 4: Dynamic aperture for mode A

When the achromatic condition was broken down, the beam emittance maybe lowers further. After linear optics matching, the low emittance mode with distributed dispersion was obtained. The figure 5 gives the beta and dispersion function. As doing before, OPA software was used in nonlinear optimization. The dynamic aperture was obtained by numerical tracking using ELEGANT. Figure 6 is the 2000 turn's dynamic aperture for on-momentum and off-momentum particle. Clearly, the dynamic aperture is enough large. The brilliance curves for this low emittance mode were plotted in figure 1.

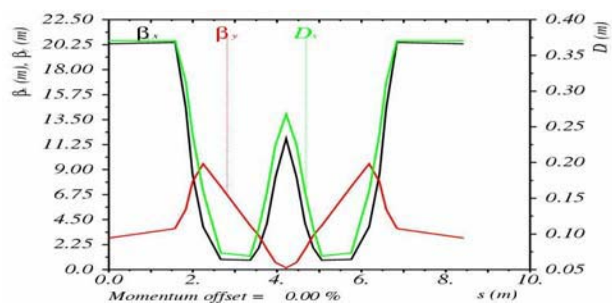

Figure 5: Beta and dispersion functions of one cell

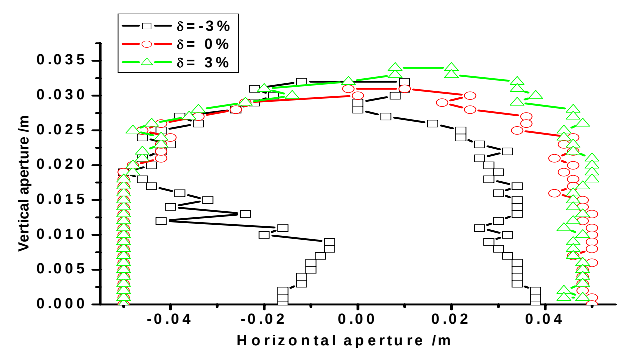

Figure 6: Dynamic aperture for mode B

ISOCHRONOUS MODE

In recent years, coherent THz radiation bursts were observed at some storage ring [10]. At some light source, stable coherent THz radiation was produced under low momentum compaction operation mode [11]. Compared with traditional THz source, the coherent THz radiation from electron beam is very powerful. This is likely to become a new scientific research tools in THz range.

In the new lattice design, an isochronous operation mode was considered as the supplementary operation mode. Due to long wavelength of THz radiation, the coherence mainly requires that bunch length is short

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enough, while the requirement on beam emittance is loose. Below instability threshold, the key to obtain short bunch length is to reduce momentum compaction factor. Through negative dispersion functions at straight section the linear momentum compaction factor can be decreased. In the linear optics matching, the quadrupoles at arc were used to adjust linear momentum compaction continuously, while the quadrupoles at straight section were used to adjust transverse tune and betatron functions. The momentum compaction factor can be varied between 10^{-3}~10^{-6} continuously, while variation of tunes and beta function is little. The figure 7 gives the beta and dispersion function of the isochronous mode with linear momentum compaction 10^{-5}.

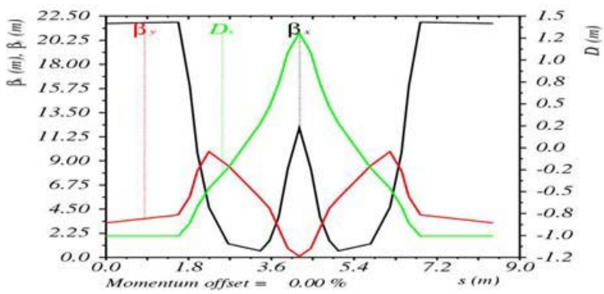

Figure 7: Beta and dispersion functions of one cell

The transverse focusing is not very strong, and the dynamic aperture is very large. In simulation, it is found that the dynamic aperture is not sensitive to the sextupole at straight section, and then these sextupole can be used to regulate the higher order momentum compaction. Table 2 summarized the main parameters of the achromatic low emittance mode (mode A), the an-achromatic low emittance mode (mode B) and the isochronous modes (mode C).

Table 2: Main parameters of new lattice

	Mode A	Mode B	Mode C
Energy (MeV)	800		
Focusing type	Separate DBA		
Circumference (m)	67.36		
Field of dipole (T)	1.5		
Critical wavelength	1.94 nm		
Number of straight line	8×3.2 m		
Radiation loss	20.3keV/turn		
Emittance (nm·rad)	7.4	3.6	~45
Transverse tunes	7.42/5.13	7.43/5.12	~7.44/5.30
Natural chromaticity	-32/-12	-31/-12	-36/-15
Momentum compaction	0.00423	0.00455	10^{-3}~10^{-6}
Energy spread (1‰)	0.51	0.51	0.51

LOCAL BUMP FOR INJECTION

The lifetime should be very poor due to the low emittance and beam energy. The full energy injection, so much as top up operation, is needed for radiation users. The detail study of injection system design would not be presented here. The maximum kick angle is about 12 mrad, which is not a very stringent requirement.

SUMMARY

An optional lattice design for the upgrade of HLS storage ring was presented. Compared with current HLS storage ring, the brilliance of the new design should be enhanced by two orders approximately; and the number of insertion devices also increased considerably. The detail study of upgrade proposal of HLS is undergoing.

REFERENCES

[1]National Synchrotron Radiation Laboratory of University of Science and Technology of China, “Development Report of Hefei Synchrotron Radiation Accelerator” (in Chinese), 1991.

[2]Zuping Liu, Qiuping Wang, Shengsheng Hu, et al, “ The construction, completion and significance of NSRL Phase II Project”, Jour. of China Univ.ofF S. & T. (in Chinese), Vol.37, p338-344(2007).

[3]Zuping Liu, Weimin Li, Hongliang Xu, et al, “Analysis of some phenomena in the commissioning of the storage ring in Phase II Project of the HLS”. HEP&NP (in Chinese), Vol.30, p72-74(2006).

[4]He Zhang, Lin Wang, Duohui He, “Design of the HLS high brilliance lattice”. HEP&NP (in Chinese), Vol.30, p138-140(2006).

[5]Lin Wang, Hongliang Xu, Guangyao Feng, et al, “Lattice design for a low energy electron storage ring”, Jour. of China Univ.ofF S. & T. (in Chinese), Vol.37, p446-450(2007).

[6]M.Katoh, K.Hayashi, T.Honda, et al, “New lattice for UVSOR”, Nucl. Instrum. Methods Phys. Res. A 467-468(2001) 68-71.

[7]Http://mad.web.cern.ch/mad/

[8]A.Streun, “OPA documentation”, Switzerland, 1997.

[9]M.Borland, “ELEGANT: A Flexible SDDS-Compliant Code for Accelerator Simulation”, Advanced Photon Source LS-287, September 2000, USA.

[10]J.M.Byrd, W.P.Leemans, A.Loftsdottir, et al, “Observation of Broadband Self-Amplified Spontaneous Coherent Terahertz Synchrotron Radiation in a Storage Ring”, Phys. Rev. Lett. 89, 224801(2002).

[11]M.Abo-Bakr, J.Feikes, K.Holldack, et al, “Brilliant, coherent far-infrared (THz) synchrotron radiation”, Phys. Rev. Lett. 90, 094801(2003).