LATTICE DESIGN AND BEAM LIFETIME STUDY FOR HLS STORAGE RING UPGRADE PROJECT*

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Abstract

HLS (Hefei Light Source) is a dedicated synchrotron radiation research facility, whose emittance is relatively large. In order to improve performance of the machine, especially getting higher brilliance synchrotron radiation and increasing the number of straight sections for insertion devices, an upgrade project is on going. A new low emittance lattice, which keeps the circumference of the ring no changing, has been studied and presented in this paper. For the upgrade project, a new ring will be installed on current ground settlement of HLS and all of the magnets will be reconstructed. After optimization, two operation modes have been chosen for different users. Nonlinear dynamics shows that dynamic aperture for on-momentum and off-momentum particle is large enough. Beam lifetime has also been studied. Calculation results proves that expected beam lifetime about 8.5 hours can be obtained with a fourth harmonic cavity operation.

INTRODUCTION

HLS is a typical 2nd generation synchrotron radiation light source. A 200MeV electron linear accelerator, an 800MeV electron storage ring and a beam transport line are the main component parts about the machine. Phase I project of HLS was finished in 1989 [1], which marks that the first dedicated synchrotron radiation light source has been fulfilled in china. From 1999 to end of 2004, Phase II Upgrade Project [2] of HLS was carried out in order to improve the machine reliability and install more beamlines for users. For the operating machine, beam emittance of the lattice is 160nm·rad. The magnet lattice is a TBA structure with 4 super periods and transverse tunes are 3.54 and 2.60 respectively, which means only 4 straight sections can be used to install insertion devices or injection system. With the current situation of HLS, an upgrade project was brought forward one year ago, which main purpose is to improve the machine's performance. Comparing with 2nd generation synchrotron light sources in the world, there are three considering aspects for this project. First, a new lattice should be found to reduce beam emittance to get higher brilliance synchrotron radiation for users. Second, more straight sections are needed for installing wiggler or undulators. Third, beam orbit stability should be improved to guarantee the radiation's quality. Some systems such as magnet system will be rebuilt to meet the project requirement. Considering time limitation of the project, the new ring will be installed on current ground settlement of HLS, which means circumference of the ring will keep 66.13m as current situation.

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LINEAR OPTICS

Several lattices have been studied over the past years. As work progressed, it became clear that DBA lattice could meet the emittance purpose while providing an increased number of insertion device straight sections.

In this way, a DBA with 4 periods was chosen as the lattice structure. There are 8 straight sections along the ring. Four short straight sections about 2.3m in chromatic arcs can be used besides four 4.0m long achromatic straight sections. There are eight quadrupoles in each cell. 4 quadrupoles are located in chromatic arcs and others in long straight section which can be used to adjust tunes and β function. In order to lengthen straight sections, combined function sextupoles are chosen to save space along the ring. Sextupoles can not only compensate chromaticity and harmonics, but correct closed orbit distortion and transverse coupling by providing dipole and skew quadrupole field components. The magnet layout of the ring is shown in Figure 1.

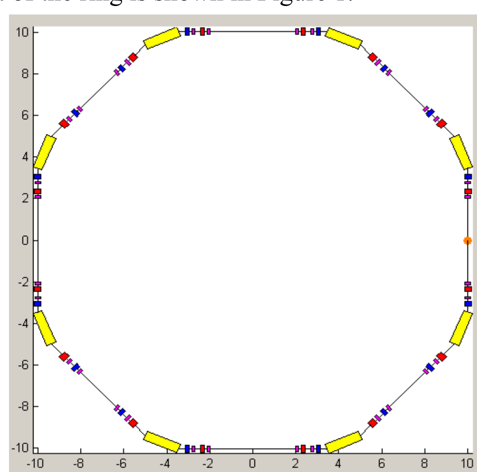


Figure 1: Magnet layout of HLS II storage ring.

Two operation modes (mode A and mode B) have been optimized. Mode A is an achromatic mode, whose dispersion in the long straight section is zero. Mode B is a distributed dispersion mode, whose emittance is smaller than that of mode A. Table1 shows list of the linear lattice about the two modes in half cell. β and dispersion functions of the two modes are shown in Figure2 and 3. Table2 gives main parameters of the storage ring. From above results, one can see that there are same tunes in the two modes although their beam emittances are quite different. This means one can easy get Mode B from Mode A by lattice tuning.

Table 1: List of The Linear Lattice (Half cell)

	Mode A	Mode B
Start point of each cell	Midpoint of long straight sections	
DL	2.003175m	
Q1	0.20m/3.8807 1/m^2	0.20m/3.8278 1/m^2
DQ1	0.50m	
Q2	0.20m/-3.2031 1/m^2	0.20m/-3.1959 1/m^2
DBQ1	0.30m	
B	1.7m/1.2336T	
DBQ2	0.70m	
Q3	0.30m/3.7871 1/m^2	0.30m/3.8482 1/m^2
DQ2	0.50m	
Q4	0.20m/-3.3874 1/m^2	0.20m/-3.3857 1/m^2
DM	1.163175m	
symmetric point	Midpoint of short straight sections	

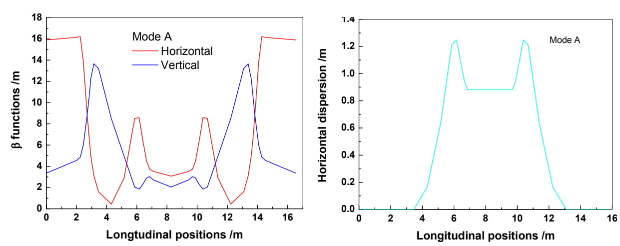


Figure 2: β and dispersion function of mode A.

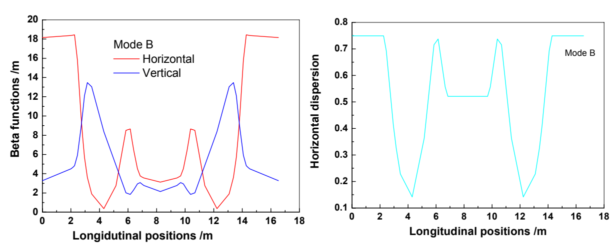


Figure 3: β and dispersion function of mode B.

Table 2: Storage Ring Parameters

	Mode A	Mode B
Energy [GeV]	0.8	
Circumference [m]	66.13	
DBA cells	4	
Bending radius [m]	2.1645	
RF frequency [MHz]	204.0	
Energy spread	0.00047	
Emittance [nm·rad]	36	20
Beam current	>300mA	
Momentum compaction	0.0205	0.0184
Tunes: ν_x, ν_y	4.44/2.81	4.44/2.81
Natural chromaticity: ξ_x, ξ_y	-9.89/-4.67	-10.8/-4.64
Maximum dispersion [m]	1.2	0.75
Radiation loss [keV/turns]	16.74	
Dipole critical energy [eV]	525	

NONLINEAR DYNAMICS

Four families sextupoles per-cell are used to correct chromaticity and harmonics. Two of them flank the long straight section. Others located between two adjacent quadrupoles shown as Figure 1. Because number and position of sextupoles are restricted, nonlinear dynamics can be optimized by adjusting tunes and betatron phase advances. In Mode B, sextupoles in long straight sections can also affect chromaticity. Considering factors about high order chromaticities, amplitude dependant tune shifts and high order resonance modes [3,5], optimized results about sextupoles strength are shown in Table 3. Figure 4 shows dynamic aperture (DA) for δ= 0, ±2 % and transverse amplitudes at the long straight section for Mode A. As to Mode B, DA is also large enough. The frequency map for the optimized tune and sextupole settings for 1.0 linear chromaticity is shown in Figure 5 with the diffusion parameter plotted as a color-weighted value. Elegent code has been used to calculate DA with errors. All of the maximum misalignment errors of magnets are settled 0.15mm and rotation errors 0.2mrad. Fields relative errors are settled 0.1%. Fields errors for random mutipoles and systematic multipoles are referred to parameters of SSRF and SPEAR3. 300 seeds are

Table 3: Parameters of Sextupoles

	Mode A	Mode B
S_1 [1/m^3]	0.00	8.79
S_2 [1/m^3]	0.00	-11.36
S_3 [1/m^3]	49.36	49.00
S_4 [1/m^3]	-79.07	-79.00

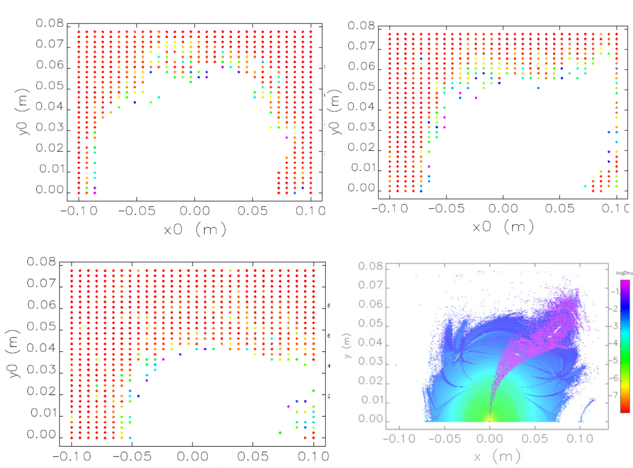
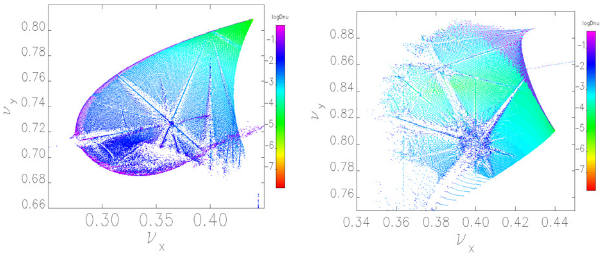


Figure 4: Dynamic aperture for δ= 0, ±2% and transverse amplitudes at the long straight section (Mode A, 1000turns)

simulated by tracking 1000 turns. Results prove that DA in horizontal plane can reach about 40mm with δ =0,-2%, and 30mm with δ =+2% for the two modes.



Mode A Mode B

Figure 5: Frequency map of the two modes.

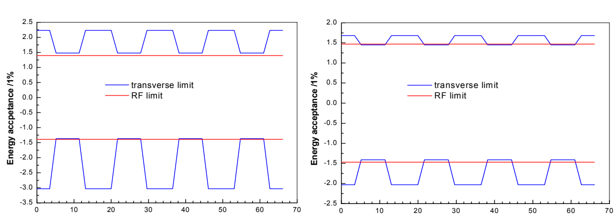
BEAM LIFETIME STUDY

Momentum Acceptance (MA)

The RF bucket MA can be given as a function of cavity voltage and is invariable along the lattice structure. Another restriction is the lattice MA which is determined by physical aperture or dynamic aperture. Because the lattice MA depends on the scattering locations, it is not a constant along the lattice and it can be given as [4]

$$\delta^{L}_{acc}(s_0)=\min_{i=1...N}\left\{\frac{a_{xi}}{\sqrt{H_0\beta_{xi}}+\eta_i}\right\}$$

with $\delta=\Delta p/p_0$, H_0 is Courant-Snyder invariant at s_0 where scattering occurred, β_{xi},η_i,a_{xi} corresponding horizontal beta function, dispersion and vacuum chamber's half width respectively. The above equation can be satisfied for a perfectly linear and chromaticity corrected lattice. Figure 6 shows the MA distribution of two modes. It seems that MA limit is (+1.48%, -1.37%) for Mode A and (+1.45%, -1.41%) for Mode B.



Mode A Mode B

Figure 6: MA distribution along the ring.

Beam Lifetime Calculation

Usually beam quantum lifetime depends on beam transverse size and energy spread. When transverse acceptance of the ring is much larger than the beam size and MA is much larger than energy spread, quantum lifetime will be too long to consider.

Elastic scattering effect is related with beam energy and linear lattice. High beam energy and low average β function can decrease elastic scattering beam loss efficiency. Inelastic scattering effect depends on the MA of the ring. Considering the above two factors, gas scattering lifetime is 24.8h for Mode A and 23.5h for Mode B.

As we know, Touschek lifetime is in direct proportion to the square of momentum acceptance (MA) and to bunch volume. Tracking has been done for 500 turns. 204.0MHz RF frequency, 250kV cavity voltage, 1.5nC charge per bunch and 5% betatron coupling are used for calculating the Touschek lifetime. Installing a 4th harmonic cavity is one of the effective methods to increase beam Touschek lifetime, which can lengthen the bunch to get a larger beam volume. Conservative estimation, the Touschek lifetime can be increase by a factor of 2 with the cavity working. In this way, the beam lifetimes have been given in Table 4. In the future, top up injection operation will be applied to keep bunch current within the required value.

Table 4: Estimation of Beam Lifetime

	Mode A	**Mode B**
Quantum lifetime	Long enough	Long enough
Gas scattering lifetime	24.8h	23.5h
Touschek lifetime	6.5h	4.3h
Touschek lifetime (with 4th harmonic cavity)	~13h	~8.6h
Total lifetime	8.53h	6.30h

SUMMARY

An optional lattice design and beam lifetime study for the upgrade project of HLS was presented. Compared with current HLS storage ring, the brilliance of the new design should be enhanced by several ten times, and the number of insertion devices is also increased considerably. The detail study of the upgrade project is undergoing.

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