Design of the HLS High Brilliance Lattice*

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Abstract Several new high brilliance lattices of the HLS storage ring are proposed. The magnetic lattices are designed with the constraints that the positions of all the elements and beamlines in the storage ring are kept unchanged and no new element is used. Small beam emittances can be achieved step by step. In these lattices, all of the straight sections have small vertical beta function, which are suitable for the operation of insertion devices. Tracking study shows that the new lattices have sufficiently large dynamic apertures for injection and storage.

Key words high brilliance, low emittance, Lattice, storage ring

1 Introduction

Hefei Light Source (HLS) contains a 200MeV Linac and an 800MeV storage ring. The storage ring consists of four triple bend achromat (TBA) cells and four 3m long straight sections. A superconducting wiggler and an undulator are installed. Currently There are 14 beamlines in operation.

Now the natural horizontal emittance of HLS is 137nm·rad. A high brilliance lattice was designed in the Phase II project of HLS, which reduces the emittance to 27nm·rad.[1] But in the commissioning, we found the old design had some shortcomings. (1) Two of the straight sections have high vertical beta functions, which are unsuitable to the operation of insertion devices. (2) Two groups of quadrupoles have too high magnetic strengths, resulting in high power supply current and too high temperature. (3) The horizontal tune is close to super-periodic structural resonance.[2] So we designed new high brilliance lattices to avoid these problems and achieve lower emittance. The requirements for the new lattices are listed in the following. (1) All of the four long straight sections have low vertical beta function. (2) All the quadrupole coefficients are less than 4.3m^{-2} with $B\rho = 2.67\text{T·m}$. (3) Proper tunes. (4) Low emittance. (5) The positions of all elements in the storage ring and beamlines are kept unchanged, and no new element is added to the ring. Three kinds of lattices are discussed in this paper.

2 Linear Lattice

One TBA cell of HLS contains three dipoles, eight quadrupoles (four families), and four sextupoles (two families). The strengths of quadrupoles are given in Table 1. All quadrupoles have the strength less than 4.3m^{-2} in order to avoid the difficulties in controlling the temperatures of them. Fig. 1 illustrates the beta and dispersion functions in one cell of the three lattices. In the straight sections of the lattice 1, $\beta_y = 0.51$m, $\beta_x = 25.45$m, and $\eta_x = -0.295$m. In the lattice 2, $\beta_y = 0.78$m, $\beta_x = 33.04$m, and $\eta_x = -0.215$m. And in the lattice 3, $\beta_y = 1.14$m, $\beta_x = 40.61$m, and $\eta_x = -0.044$m. The low vertical beta functions help to reduce sensitivity to the effect of insertion devices, and therefore are suitable for the operation of insertion devices, even the in-vacuum insertion devices. All the three lattices have negative dispertion functions in the straight sections.

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They can be changed to zero or slightly positive to get lower emittance. But we leave them there with the benefit of good separation of beta functions in the sextupoles that lead to lower sextupole strength.

Table 1. Main parameters of HLS high brilliance lattices.

	Lattice 1	Lattice 2	Lattice 3
$Q1/m^{-2}$	2.7496	2.6790	2.6148
$Q2/m^{-2}$	-2.8876	-2.7968	-2.7004
$Q3/m^{-2}$	3.7620	4.0591	4.2914
$Q4/m^{-2}$	-1.1581	-1.5225	-1.7782
Tunes	(5.197, 2.528)	(5.205,2.545)	(5.207, 2.535)
α_p	0.0205	0.0168	0.0134
$\xi_{x0,y0}$	(-13.53,-11.80)	(-16.02, -8.65)	(-18.32, -6.98)
$\varepsilon_{x,0}$/(nm·rad)	42.33	25.71	16.15

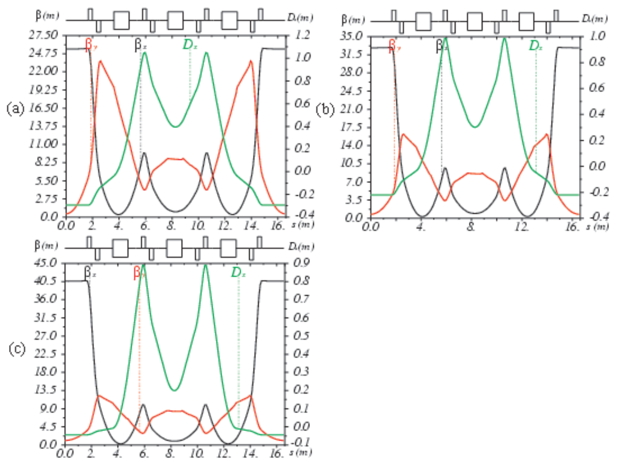

Fig. 1. One cell optics of (a) Lattice 1, (b) Lattice 2, and (c) Lattice 3.

Table 1 also shows the main parameters of the lattices. The sequential emittance values are 42.33nm·rad, 25.71nm·rad and 16.15nm·rad, while the present value is 166nm·rad, and the theoretical minimal value is 7nm·rad[3]. The tunes of the three lattices are in the same area, which make sure that we can change the operation mode from Lattice 1 to Lattice 3 gradually in commissioning. The tunes are chosen to avoid strong resonances in the working diagram, keeping proper distance to the super-periodic resonance stop bands, and obtaining large enough dynamic aperture in the vicinity of the working point.

The three lattices meet the requirements mentioned above. But the horizontal beta functions in the long straight sections in Lattice 2 and Lattice 3 are higher than 30 m, which may increase the sensitivity to errors and lead to negative effects to the injection progress and beam lifetime. The fixed element positions and the strength limits of quadrupoles give strong constraints to the lattice design. Under these constraints, the strengths of Q3 and Q4 are almost determined by the emittance[4]. So we only have Q1 and Q2 to adjust the beta functions. Keeping the low vertical beta functions in priority, we haven't found a method to adjust horizontal beta functions effectively. Now we are still trying to find a better lattice, but haven't got an acceptable result. The effects of the high horizontal beta functions to the injection progress and beam lifetime need particular analysis in future.

3 Chromaticity correction and dynamic aperture

Here we chose Lattice 3 as an example to discuss the nonlinear dynamic problems. Two families of sextupoles are used to control the global chromaticity. The first order chromaticity is corrected to a slightly positive value so as to avoid the head-tail instability. After the correction, tune shifts versus momentum deviations are given in Fig. 2. When dp/p changes from -0.01 to 0.01, the tune variations are less than 0.02. But when dp/p becomes larger, the tune variations increase rapidly. It is probably attributed to the effect of higher order chromaticities, since we have no other sextupoles to correct higher order chromaticities. The only thing we can do is to choose proper tunes so that strong resonance such as half integer resonance can be avoided even in the condition of large momentum deviations.

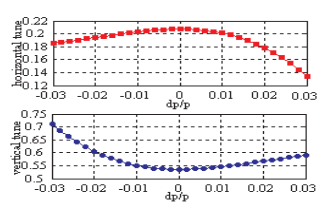

Fig. 2. Tune shifts versus momentum deviation.

Dynamic aperture studies are performed with an element-by-element tracking code, AT[5]. The reference point is positioned at the midpoint of the straight sections. Fig. 3 displays the dynamic aperture of 2048-turn tracking result from AT. To simulate the imperfect lattice, we seed the magnet lattice

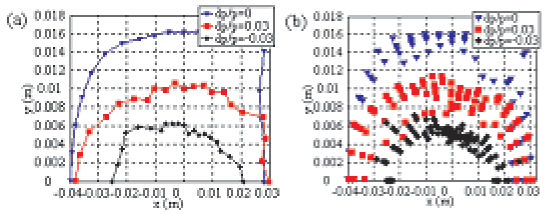

Fig. 3. (a) Dynamic aperture without errors; (b) Dynamic aperture with errors.

with three classes of errors, including misalignment errors, main field errors, and multiple errors. The tracking study was done after the closed orbit correction by AT. As Fig. 3 (b) shows, with the effect of errors, the dynamic aperture is still larger than ten times of the beam size.

4 Brilliance of SR from HLS

As the result of lower emittance, the increase of the brilliance can be achieved. Table 2 shows the caculated brilliance of the new lattices at the midpoints of the three bend magnets in one cell respectively. After the upgrade, the brilliance will increase a lot, comparing with the value of general purpose light source (GPLS) mode[6].

Table 2. Comparation with original values (HLS).

		GPLS	Lattice 1	Lattice 2	Lattice 3
Beam current/mA		150	150	150	150
xy coupling(%)		10	10	10	10
Brilliance	B1	6.4×10^{13}	2.6×10^{14}	9.4×10^{14}	3.4×10^{15}
(photons/s/mm^2	B2	6.0×10^{13}	7.9×10^{14}	2.2×10^{15}	6.1×10^{15}
/mrad^2/1%b.w.)	B3	6.4×10^{13}	2.6×10^{14}	9.4×10^{14}	3.4×10^{15}

5 Summary and conclusion

We have designed new lattices for HLS, solving the problems of the old design and achieving lower emittance. By introducing one of these lattices, HLS will be converted to a high brilliance synchrotron light source in VUV and soft X-rays, which will highly upgrade its performance.

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合肥光源高亮度模式Lattice设计*

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摘要 介绍了一组合肥光源新高亮度模式的Lattice. 新的设计维持了储存环上所有元件和光束线位置不变, 也没有加入新的元件. 取得了较低发射度. 所有直线节处的垂直方向β函数值都很小, 适合插入件的运行. 跟踪计算表明新Lattice具有足够大的动力学孔径用于注入和储存粒子.

关键词 高亮度 低发射度 Lattice 储存环

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