THEORETICAL STUDY OF MEDIUM EMITTANCE LATTICE AT HLS*

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Abstract

In order to improve the performance of Hefei Light Source (HLS), two medium emittance lattices of HLS storage ring are calculated. Lattices are designed with the HLS hardware constraints and no new hardware is used. Emittance of the lattice “w3” is 64.2 nmrad, and the “w3u” is 37.5 nmrad. The “w3u” is a non-achromatic lattice with non-zero dispersion function at long straight section. Coefficients of quadrupoles of “w3u” is designed to be similar with the “w3” in order for that “w3u” can be smoothly transited from “w3”. This can avoid the beam dynamics problem of the “w3u” lattices.

INTRODUCTION OF HEFEI LIGHT SOURCE

Hefei Light Source (HLS) is a typical 2nd generation TBA structure synchrotron radiation light source. It’s composed of a 200 MeV Linac and an 800 MeV storage ring. The emittance of the operating lattice “GPLS mode” is 133 nmrad [3][4]. In recent years, many 2nd generation synchrotron light sources have been upgraded and the emittance decreased to lower than 40 nmrad to get high brilliance synchrotron radiation [6][7]. After HLS Phase II Project [1][2], the hardware of the storage ring is upgraded and it’s possible to operate the lower emittance lattice. Because there’s no booster, it’s difficult to inject with a lower emittance lattice of which the beam dynamics characteristics is usually not good, so this paper presents two lattices: “w3” and “w3u”. Emittance of the first one is 64.2 nmrad and the second one “w3u” is 37.5 nmrad. Injection and ramping will be realized with the 64.2 nmrad lattice at the energy of 200 MeV, after ramping to 800 MeV, the lattice is shifted to 37.5 nmrad to get the high brilliance synchrotron radiation.

LINEAR OPTICS

Constraints

In order to minimize the work on hardware, positions of all elements and beamlines will be kept unchanged, and the coefficient of quadrupoles should be smaller than 4.3 m^{-2}. There are four 3-meters long straight sections, vacuum chambers of these four straight sections are narrow gapped for insertion devices, the β_y at these sections should be smaller than that of other locations.

Basic Parameters

Basic parameters of “w3” and “w3u” are shown in table 1

Table 1: Basic Parameters of “w3” and “w3u”

	w3u	w3
K_1/m^{-2}	2.04091	2.14922
K_2/m^{-2}	-1.7064	-1.88155
K_3/m^{-2}	-1.13164	-0.9961
K_4/m^{-2}	3.37658	3.2547
K_5/m^{-2}	-2.49662	-2.671
K_6/m^{-2}	4.19073	4.0783
K_7/m^{-2}	-2.72096	-2.4639
K_8/m^{-2}	2.58868	2.5405
(ν_x, ν_y)	$(4.459, 2.399)$	$(4.456, 2.402)$
α_p	0.024	0.028
$\xi_{x0,y0}$	$(-8.08, -4.41)$	$(-7.22, -3.96)$
Sext. coefficient	$(25.5, 27.9)$	$(15.4, 18.4)$
ε(nmrad)	37.5	64.2

Twiss functions $\beta_{x,y}, \eta$ are show in fig.1 and 2

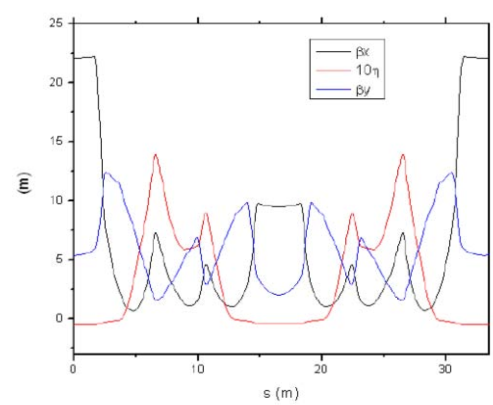

Figure 1: Twiss Parameter of “w3”

Comparing with the operating lattice ”GPLS mode”, coefficients of quadrupoles of these two lattices have following characteristics: coefficient of K1 of “w3” and “w3u” is smaller than that of “GPLS mode” and K2 is stronger to get smaller β_x at the first bending magnet B1; K3 is weaker and K4 is stronger to get smaller β_x at the second bending magnet B2, K5 becomes a defocusing magnet and K6 becomes a focusing magnet with stronger focusing coefficient to ensure the small β_x at B3.

Emittance of “w3” is 64.2 nmrad and “w3u” is 37.5 nmrad. It’s noticed that differences of corresponding

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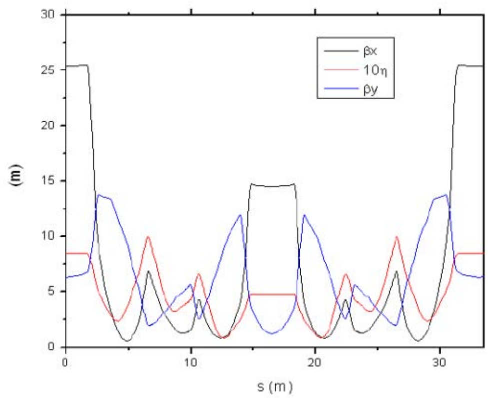

Figure 2: Twiss Parameter of "w3u"

quadrupole coefficient of two lattices are small, the maximum difference of Ki is 0.175 m^{-2}. It indicates that two lattices "w3" and "w3u" could be smoothly connected and there should exist a transition process between them. When coefficients of 8 quadrupoles change linearly from "w3" to "w3u", lattices during the process are calculated and the (ν_x, ν_y) of these intermediate lattices is plotted on the $\nu_x - \nu_y$ space as shown in fig.3, the color of points indicates the emittance, red means higher emittance, blue means lower emittance. By observing the figure, emittance of lattices during the process decreases smoothly from 64.2 nmrad to 37.5 nmrad. The range area of (ν_x, ν_y) of intermediate lattices is $\nu_x \in (4.456, 4.460), \nu_y \in (2.392, 2.402)$, it's small and there's no major resonance lines crossing the transition area.

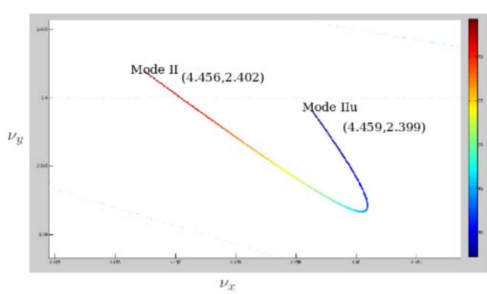

Figure 3: Transition from "w3" to "w3u"

The difference of Twiss parameters between "w3" and "w3u" is that "w3" is achromatic and "w3u" is non-achromatic. η_x of "w3u" at long straight section is about 1.03m and 0.32m, Electrons with energy spread will deviate from the ideal orbit with the formula $x = \eta\delta$. It's disadvantageous for the transverse beam dynamics, however, the lattice "w3u" is realized by an adiabatic transition process at the energy of 800 MeV, the beam dynamics requirement is not so critical than common lattice such as "w3" which needs an injection process requiring high performance of linear and nonlinear beam dynamics. If the beam orbit is controlled carefully, there will be little beam loss during the process.

Another disadvantage of non-achromatic lattice is the reduction the brilliance of Insertion Devices (IDs). There are 5 beamlines connected with insertion devices and 9 beam lines connected with bending magnets. The brilliance of IDs of "w3u" is nearly the same with "w3" by calculation. It means that, comparing with the 64.2 nmrad lattice, the 37.5 nmrad lattice will only improve the brilliance synchrotron radiation light of 9 beamlines.

β_y of "w3" at long straight section is about 2 to 3 meters, the minimum β_y is 1.8m and the maximum β_y is 9.8m, the proportion of betatron oscillation amplitude envelope at locations of long straight section, min. β_y and max. β_y is about $1.18 : 1 : 2.33$. The oscillation amplitude envelope at long straight section is only 18% larger than the min. amplitude envelope, the oscillation envelope at long straight section is nearly the minimum around the whole ring, and it's advantageous for the narrow gap at long straight sections. The max. oscillation envelope is 97% larger than the betatron oscillation envelope at injection point at y direction. It indicates that when the beam coming from transport line which connects the 200 MeV Linac and the storage ring has an amplitude error at y direction, the oscillation amplitude envelope will be enlarged by 97% at the location of maximum β_y, this is acceptable at HLS because the vacuum chamber boundary at the max. β_y locations is more than 20 mm comparing with the dimension at the long straight section 13 mm.

NON-LINEAR DYNAMICS

Dynamics Aperture of Ideal Lattices

There are two families of sextupoles to correct the chromaticity, coefficients of sextupoles which correct the chromaticity to zero are listed in table 1. Dynamic aperture of "w3" and "w3u" are shown in fig. 4 and 5. Dynamics aperture of "w3" is about 70 mm $\times$ 40 mm, much larger than the dimension of vacuum chamber which is 43 mm $\times$ 13 mm. Frequency Map Analysis (FMA) [5] of "w3" is considered, and is shown in fig. 6. The nonlinear effect is not strong because of the weak sextupole strength. Maximum order of resonance lines shown in the figure is 7th, resonance orders higher than 7 is excited in the $\nu_x - \nu_y$ space, but it won't cause the loss of particles.

The DA of "w3u" is about 50 mm $\times$ 50 mm, also larger than the vacuum chamber dimension. Because this lattice is realized by an adiabatic transition process from "w3" at the energy of 800 MeV at which electrons have been damped, the oscillation amplitude is small, so the beam dynamics requirement is not lower than that of "w3".

Dynamics Aperture of Lattices with Errors

Dynamic aperture of "w3" with errors including misalignment errors, main field errors and energy spread is analyzed. We calculated the dynamic aperture with 20 families of errors, the maximum error considered in the tracking

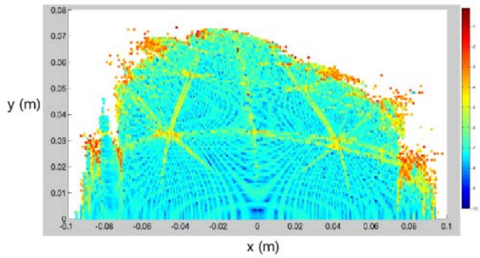

Figure 4: Dynamic Aperture of “w3”

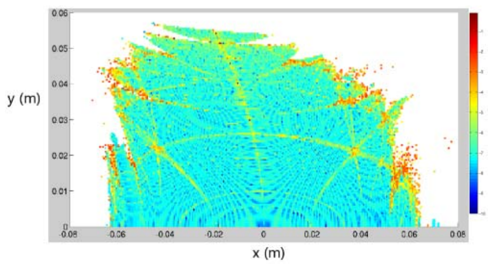

Figure 5: Dynamic Aperture of “w3u”

program is shown in table 2, the max. energy spread is considered to be $\pm 1.5\%$ in calculation.

The dynamic aperture of “w3” with errors is shown in fig. 7, the dynamic aperture is still larger than the bounding of vacuum chamber.

Beam Lifetime

One critical problem of the “w3u” is the short Touschek lifetime which is only about 3 to 4 hours at the energy of 800 MeV and the beam current of 200 mA , it’s difficult to operate the lattice under this short lifetime. One method to solve this problem is adding a 3rd order RF cavity to lengthen the bunch length to decrease the electron density in the bunch.

CONCLUSION AND FUTURE WORK

Two lattices introduced in the paper satisfy the hardware constraints. The 64.2 nmrad lattice “w3” performs well from theoretical analysis. Emittance can be reduced to 37.5 nmrad by a transition process to avoid the beam dynamics

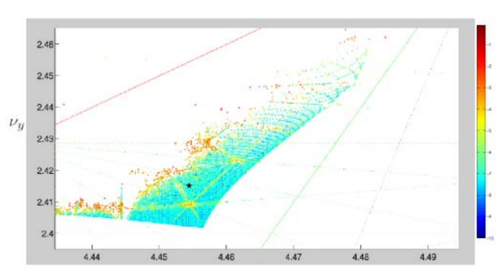

Figure 6: FMA of ”w3”

Table 2: Errors of Main Magnets

	Δx (mm)	Δy (mm)	$\Delta\psi$ (mrad)	Field Errors
Dipole	0.5	0.5	0.2	$\Delta K/K$ 5×10^{-4}
Quadrupole	0.5	0.5	0.5	$\Delta B/B_0$ 0.5×10^{-4}

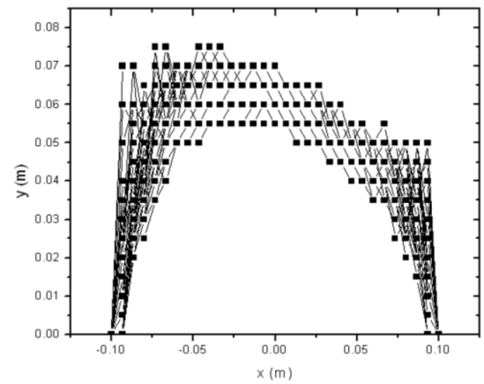

Figure 7: Dynamic Aperture of “w3” with Errors

problem of injection and ramping of low emittance.

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