COMMISSIONING OF MEDIUM EMITTANCE LATTICE OF HLS STORAGE RING *

Guangyao Feng, Lin Wang, Shancai Zhang, Hongliang Xu, Weimin Li, Zuping Liu
National Synchrotron Radiation Lab., Hefei, Anhui, 230029, P. R. China

Abstract

Hefei Light Source (HLS) is a second generation light source, whose emittance is about 160 nmrad in normal optics. Lowering beam emittance is the most effective measure to enhance light source brilliance. Considering beam lifetime limitation, a lattice with medium beam emittance was brought forward. Through distributed dispersion in straight section, the beam emittance was reduced to 80 nmrad. At same time, the betatron tunes were kept same as before. In this way, the focusing parameters can be tuned to new one smoothly. With the new lattice parameters, the brilliance of HLS is increased by two factors.

INTRODUCTION

Hefei Light Source (HLS) is a typical second generation synchrotron radiation light source. It is composed of a 200MeV linac and a 800MeV storage ring. After electron beam has been injected into the storage ring, ramping process can increase beam energy from 200MeV to 800MeV. In order to improve the performance of HLS, Phase II Upgrade Project has been finished in recent years[2]. Hardwares such as power supply, injection system, RF cavity, etc. have been upgraded, which can make the machine operate more reliably. Main parameters of HLS storage ring is shown in table1[1]. This operating mode is usually called GPLS mode. In this mode, electron beam emittance is about 160nmrad which is one of the most effective measure about HLS brilliance. Using SPECTRA, we can get that when beam current is 250mA, the bending magnet radiation brilliance is about 10^{12}, and the superconductor wiggler radiation is at the same level. The undulator radiation is about 10^{16}.

To get synchrotron radiation with higher brilliance is almost the same purpose of many second generation synchrotron light sources. Formula 1 and 2 show the brilliance equations about dipole radiation and insertion device radiation respectively[3].

$$B = \frac{F'}{(4\pi)^{\frac{3}{4}}\Sigma_x\Sigma_y\Sigma_{y'}} \approx \frac{F'}{(4\pi)^{\frac{3}{4}}\sqrt{\beta_x\varepsilon_x + (\eta_x\delta)^2}\cdot\varepsilon_y} = \frac{F'}{(4\pi)^{\frac{3}{4}}\sqrt{\beta_x\varepsilon_x + (\eta_x\delta)^2}\cdot\kappa\varepsilon_x} \quad (1)$$

*Work supported by National Science Foundation of China (10675116)
#fenggy@ustc.edu.cn

$$B = \frac{F}{(4\pi)^2\Sigma_x\Sigma_{x'}\Sigma_y\Sigma_{y'}} \approx \frac{F}{(4\pi)^2\varepsilon_x\varepsilon_y} = \frac{F}{(4\pi)^2\kappa\varepsilon_x{}^2} \quad (2)$$

Table 1: Main parameters of HLS storage ring

Parameter	Value
Circumference (m)	~66
Lattice Structure (×4)	TBA
RF Frequency (MHz)	204.016
Straight Section (m×4)	3.3
Bending Magnets Field (T)	1.2
Injection Beam Energy (MeV)	200
Operation Beam Energy (MeV)	800
Beam Current (mA)	~250
Emittance (nmrad)	~160
Tune ν_x/ν_y	3.54/2.57
Momentum Compaction Factor	0.0444
Radiation Loss per Turn (keV)	16.3
Critical Wavelength Dipole (nm)	2.4

From above formulas, conclusion can be drawn that the brilliance is in direct proportion to beam current and inverse proportion to emittance coupling coefficient. In addition, it is also inverse proportion to $\varepsilon_x^{3/2}$or ε_x^2 for different type of radiation. One side, it is difficult to increase beam current to enhance the brilliance because of electron beam collective instabilities. On the other, beam lifetime restricts the coupling coefficient decreasing. So the most realizable and effective method getting high brilliance is to optimize the focusing parameters to get lower beam emittance. This method becomes possible because of the machine operation's stability after Phase II Upgrade Project.

FOCUSING STRUCTURE STUDY

Basic parameters of the GPLS mode are shown in table2. Beta (β_x,β_y)and dispersion (D_x) functions can be seen in figure1 and figure2. In this operation mode, dynamic aperture is large enough shown in figure3 because the focusing parameters are not very strong.

Table 2: Basic parameters of GPLS and new modes

Parameters	GPLS Mode	New Mode
$K_1(m^{-2})$	1.5924	1.9591
$K_2(m^{-2})$	-1.019	-1.7337
$K_3(m^{-2})$	-2.3114	-0.7264
$K_4(m^{-2})$	3.1004	2.2011
$K_5(m^{-2})$	3.1054	3.0088
$K_6(m^{-2})$	-2.3146	-1.9690
$K_7(m^{-2})$	-1.0206	-1.8501
$K_8(m^{-2})$	1.5924	2.0473
ν_x / ν_y	3.544 / 2.572	3.540/2.571
ε_x(nmrad)	~160	80

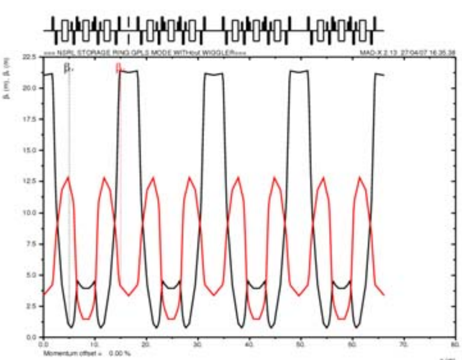

Figure 1: Beta function for GPLS mode.

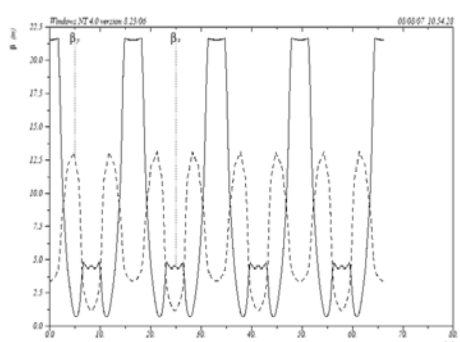

Figure 2: Dispersion function for GPLS mode.

If only the focusing parameters have been optimized without changing the elements structure and beam energy, there are two ways to get a lower emittance operation mode which can be seen from formula3. one is to strengthen the transverse focusing parameters, which has been studied in recent years[4,5,6]. Experiments have been showed it is very difficult to inject with a lower emittance lattice. This indicates that beam dynamic characters are not good because of the low injecting beam energy. This study is having in hand. Another method is to make the dispersion function at straight sections not zero. Formula3 shows that a lower emittance lattice can be got when the

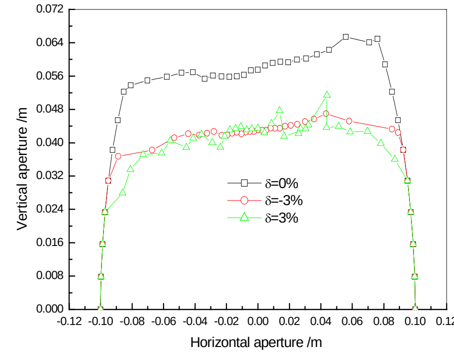

Figure 3: Dynamic aperture for GPLS mode.

dispersion function in bending magnet is appropriate. This can be realized by breaking down the achromatic condition. Lattice optimizing will be presented next.

$$\varepsilon_x = \frac{C_q \gamma^2 \langle H \rangle_{dipole}}{J_x \rho} \qquad (3)$$

$$H(s) = \gamma(s)\eta_x(s)^2 + 2\alpha(s)\eta_x(s)\eta_x'(s) + \beta(s)\eta_x'^2(s)$$

Because the injection and damping process in GPLS mode are very satisfying, they are not be changed in the new mode. After electron beam ramping to 800MeV, A smooth transition process from GPLS mode to the new one will be carried through. There are two limits about the transition to make this work easy realizing. One is to keep transverse tune varying in a very small area, which can avoid crossing major resonance lines during the transition process. Another is to keep the quadrupoles remaining their focusing property, which can economize machine study time. After optimizing, a new lattice with no zero dispersion at straight sections has been obtained. Table2 shows main parameters of the medium emittance operation mode. Comparing with the GPLS mode, $\Delta K_{max}=1.6m^{-2}$ and $\Delta K_{min}=0.1m^{-2}$. Beta and dispersion functions are shown in figure4 and figure5. OPA software

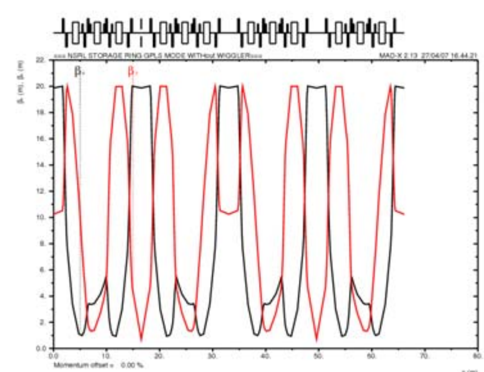

Figure 4: Beta function for the new mode.

has been used to optimize the nonlinear beam dynamics. Figure 6 gives the dynamic aperture for on-momentum and off-momentum aperture at the middle of straight section, which is calculated by MAD. Obviously, the dynamic aperture is large enough.

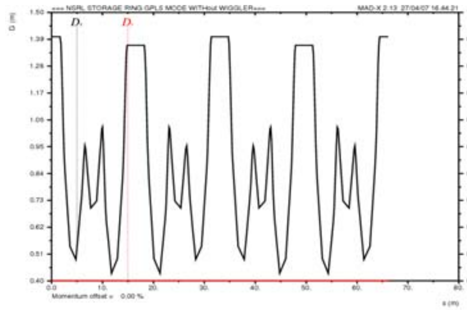

Figure 5: Dispersion function for the new mode.

Calculation proves that if coefficients of all the quadrupoles change linearly from GPLS mode to the new one, the work point should have crossed major resonance lines. So the work point's path should be optimized. Six middle points are fixed between start point and end. K_3, K_6, K_7 have been adjusted to keep $\Delta\nu_x$ and $\Delta\nu_y$ being small values while other quadrupoles' coefficients being changed linearly. Between every two neighbor points, all of the coefficients are changed linearly. Tune's variety

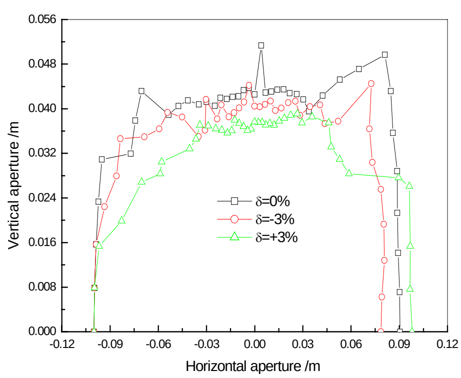

Figure 6: Dynamic aperture for the new mode.

during the transition is showed in Figure7. $\Delta\nu_{xmax}$=0.025 and $\Delta\nu_{ymax}$=0.031 prove that there is no any major resonance lines crossed.

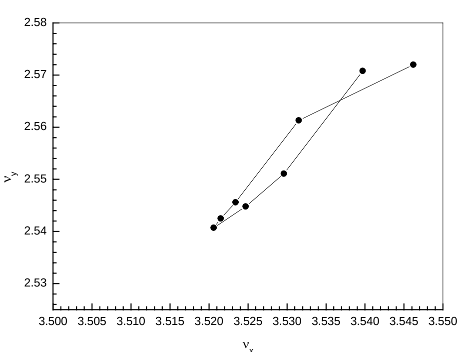

Figure 7: Tune's variety during the transition.

MACHINE STUDY

Machine study about the medium emittance operation mode has been finished successfully because of it's realizability. Figure 8 shows beam current and lifetime during the injection, ramping and mode transition process. Some conclusion can be drawn: 1) Beam losing dose not occurred during the mode transition process. 2) The mode transition process is repeatable well. 3) Higher brilliance radiation has been observed when operating in the medium emittance mode. Averagely the brilliance of HLS is increased by two factors.

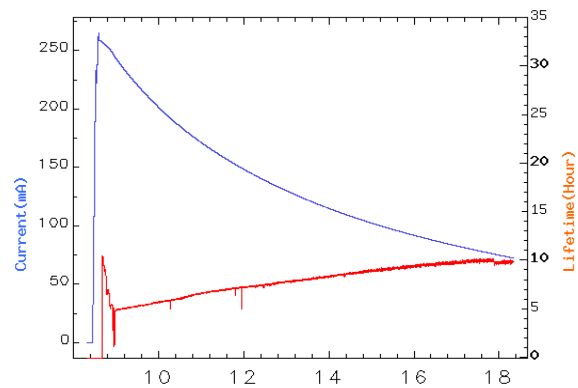

Figure 8: Beam current and lifetime.

FUTURE WORK

One of the future work is to short the time of mode transition, which can be settled by combining the ramping and mode transition process properly. Another is the problem of short beam lifetime because of smaller beam size. There are three methods being studied now: increasing RF cavity voltage, Adding new skew quadrupoles and design a 3rd order RF cavity.

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