EMITTANCE REDUCTION APPROACHES FOR NSLS-II *

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Abstract

NSLS-II is a third generation light source that is under construction at the Brookhaven National Laboratory. This paper will discuss the future emittance reduction approaches for NSLS-II. One option is installing more damping wigglers; an alternative solution is to manipulate the damping partition by shifting the chromatic quadrupoles radially. Both methods can lower the emittance effectively; however, the second method does not occupy the user straights. When the quadrupoles are moved, the orbit and thus the vacuum chambers need to be redesigned, and beam dynamics could be affected. In the paper we will compare the lattice properties for the two options, and address the potential issues.

INTRODUCTION

NSLS-II is a third-generation light source that has entered installation phase at the Brookhaven National Laboratory [1]. The 3GeV 792m long storage ring is composed of 30 double-bend-achromatic (DBA) cells and has 15 superperiods. The alternating long and short straights have lengths 9.3 m (high β_x and low β_y) and 6.6 m (low β_x and β_y), respectively. The lattice without insertion devices has 2nm horizontal emittance. Three 7m-long damping wigglers (DW) will be installed at day-one to lower the horizontal emittance below 1nm. The vertical emittance is chosen to be the diffraction limit for 1 Angstrom radiation, i.e. 8 pm. The main parameters of the superconducting rf system are f=500 MHz, h_{rf}=1320, and V = 3MV is used for all the calculations in this paper.

As shown in Fig. 1 the basic module of the NSLS-II lattice is a standard double-bend-achromatic (DBA) cell. There are three quadrupoles in each of the two matching sections, and two quadrupole doublets in the arc section. There are three sextupole families on each of the three multipole girders, which amounts to nine totally. When the emittance is ∼1nm, beam-size contribution from the momentum spread is 20% increase per cm of dispersion; therefore the DBA is designed to be a strict achromatic structure. This gives some convenience to operating the lattice at different energy because the orbit would change only in-between the two dipoles where the dispersion is nonzero. And the insertion devices and the user beam line will not be perturbed by the changes in the arc section.

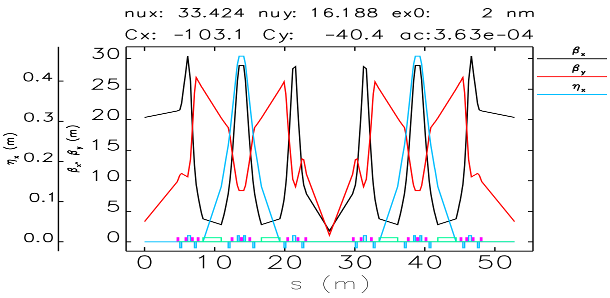

Figure 1: One superperiod of the NSLS-II DBA lattice. The magnets in the arc are named as: QM1,SM1,QM2,SM2,QM2,SM1 and QM1.

EMITTANCE REDUCTION THROUGH MORE DAMPING WIGGLERS

The first approach to further reduce the NSLS-II emittance is to install more damping wigglers. Technically there are no showstoppers. The lattice can still maintain a 3-fold symmetry if six damping wigglers are installed with two DWs placed in every one-third of the ring. The lattice parameters are listed in Table 1 when the length of the deployed DW increases.

Table 1: Lattice-Parameter Variation with Damping-Wiggler Length L_{DW}

L_{DW}	ϵ_x	σ_δ	τ_x	τ_E	E_{loss}	ν_s	σ_t
m	nm	10^{-4}	ms	ms	MeV	10^{-3}	ps
0	2	5.1	55.3	27.7	0.0191	8.71	9.0
21	0.87	8.3	23.5	11.8	0.673	8.62	15.0
28	0.73	8.6	19.7	9.9	0.803	8.57	15.6
35	0.63	8.8	17.0	8.5	0.932	8.51	16.1
42	0.55	9.0	14.9	7.5	1.062	8.44	16.6

MANIPULATION OF DAMPING PARTITION

It is well-know that the damping partition can be adjusted to lower the horizontal emittance [2]. The Damping partition is given by

$$\mathfrak{D} = \frac{1}{2\pi}\oint \frac{\eta(s)}{\rho}\left[\frac{1}{\rho^2}+2K_1(s)\right]\left[\oint \frac{ds}{\rho^2}\right]^{-1} ds. \qquad (1)$$

Note that $\mathfrak{D}$ depends on the dispersion $\eta(s)$ and the quadrupole strength $K_1(s)$; therefore the most effective way to enhance $\mathfrak{D}$ is to introduce a gradient dipole at the maximum dispersion location. For NSLS-II this can be realized by offsetting the orbit in QM2, the focusing quadrupole near the center of the arc. To increase J_x, $\mathfrak{D}$

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has to be negative. For QM2, $\eta(s) > 0$ and $K_1 > 0$, therefore ρ, or the kick has to be negative. To compensate the kick, the dipole strength must be increased. This manipulation is similar to storing beam at lower energy. As is mentioned above, the achromatic structure helps in that the beam orbit is not perturbed in the insertion straights. When J_x increases, J_E will decrease, therefore the momentum spread will grow. NSLS-II is designed with weak dipoles (B=0.4T), and the momentum spread is small due to the small quantum excitation. We will see later that the longitudinal phase space parameters can still be kept within reasonable ranges when damping partition is varied.

To gain some insight of this scheme, we worked out a solution for a 15-fold symmetric lattice without DW. The lattice functions are shown in Fig. 2. In this lattice the dipole strength is increased by 2.5mr, and QM2 is moved to produce a dipole component of -2.5mr. The quadrupoles are slightly tuned to match the dispersion function and to restore the minimum emittance condition. One can compare this lattice with Fig. 1, which is the same lattice before we apply the changes. It can be seen from the plots that lattice functions are very similar, however, the emittance is lowered by a factor of 2. On the top of the pictures the ring tune (not optimized), momentum compaction factor and natural chromaticities are also shown. The chromaticity change is small, which is crucial for the nonlinear optimization; the momentum compaction factor is lowered by 20%, which might be a negative effect because the longitudinal focusing is weakened.

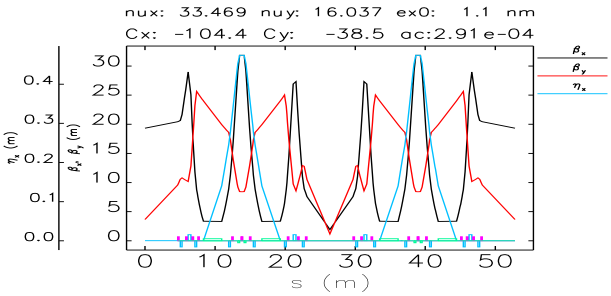

Figure 2: Lattice solution with a kick of 2.5mr in QM2.

We would like to point out that the magnets in the arc section have to be moved to keep the beam on-center. For the solution shown in Fig. 2, the needed displacements are: QM1: -2.5mm, SM1: -3.4 mm, and SM2: -5.1mm. Here the negative sign means shifting towards the center of the ring. The quadrupole strength of QM2 is $K_1L = 0.35m^{-1}$. To get a kick of -2.5mr, the beam must be off-centered to $\Delta x = -7.1$mm; therefore QM2 has to be shifted outwards by 2mm. Another effect of the orbit distortion is that the circumference increases by 0.75mm, and the rf frequency has to be lowered by about 500 Hz.

The photon absorbers in the arc will not work as expected since the orbit is moved significantly; therefore they have to be redesigned. The dipole radiation users will not be affected; however, the three-pole wiggler located in the arc will radiate at a deviated angle of 2.5 mr. This probably cannot be tolerated by the current design. A solution is the users can use the radiation from QM2.

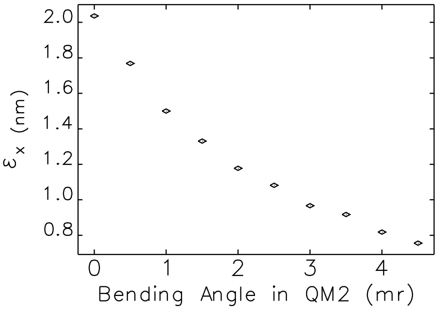

Figure 3: Emittance reduction for the lattice without DW.

We have varied the bending angle in QM2, and re-tuned several lattices. Fig.3 shows the emittance of these lattices as a function of the bending angle. For convenience we have dropped the minus sign of the angle in all the plots. The emittance reduction rate decreases when the bending angle gets bigger. The limit of this approach is really the aperture of QM2 magnet. QM2 has a bore radius of 45mm, and it is designed to have 30mm good field region. In principle it should not be a problem to move the beam by 7mm, however the Touschek scattered particles might be lost when the orbit is shifted, due to their large transverse excursion.

It is possible that we increase only the dipole strength, and leave the multipole magnets where they are. In that way the orbit will be off-center in all the multipole magnets in the arc, the emittance will also be reduced, however, the nonlinear beam dynamics might be affected. We will leave the detailed study in the future.

WORKING ON THE BASELINE LATTICE

We have also applied this method to the baseline lattice, i.e., the lattice with 3 DWs. Fig.4 shows the emittance reduction when the bending angle is varied. The method is not as effective because of the contribution of $\oint ds/\rho^2$ from the the damping wigglers. At the same bending angle 2.5mr, the emittance is reduced by a factor of 30% only. Comparing this result with the numbers in Table 1, one finds that 30% reduction is similar to the emittance reduction of 2 additional damping wigglers. The energy loss per turn is plotted in Fig.5. Again by comparing the 2.5

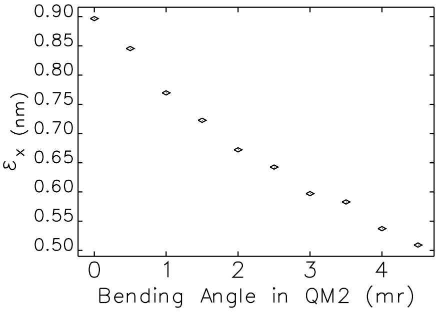

Figure 4: Emittance reduction for the baseline lattice.

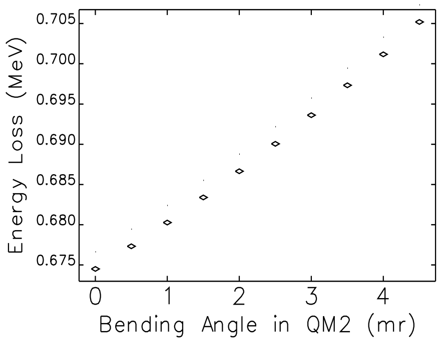

Figure 5: Energy loss per turn as a function of the bending angle.

mr case with the 35m DW configuration, one finds that the energy loss is about 25% less for the damping partition approach. Therefore the rf power is saved significantly for the damping partition method. The damping partition variation is plotted in Fig. 6. It exceeds -0.5 at about 4mr.

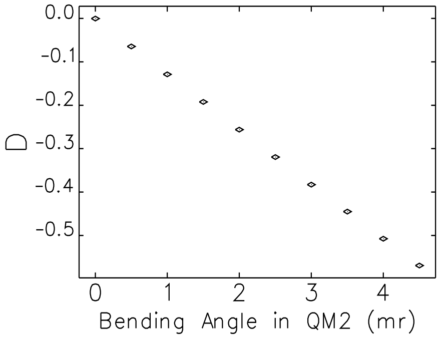

Figure 6: The damping partition parameter $\mathfrak{D}$ versus bending angle

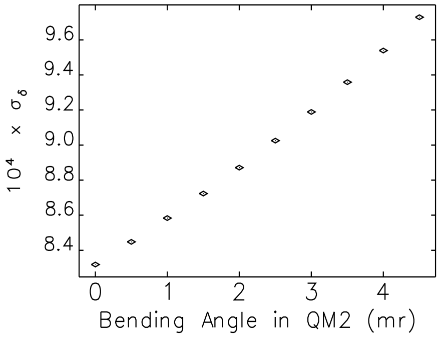

Figure 7: The momentum spread variation versus the bending angle.

Figure 7 shows the equilibrium momentum spread growth when the bending angle increases. The momentum spread at 2.5 mr is slightly larger than the 35m damping wiggler case, however, the number is still similar to the typical value in a 3rd generation light source.

The momentum compaction factor, the longitudinal damping time, and the longitudinal tune are plotted in Fig. 8, 9, 10. Even though the momentum compaction factor is reduced, the longitudinal tune is kept in a reasonable range.

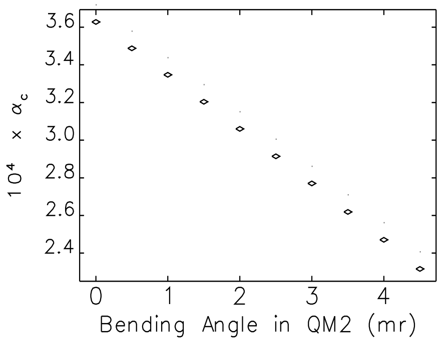

Figure 8: The momentum compaction variation versus the bending angle.

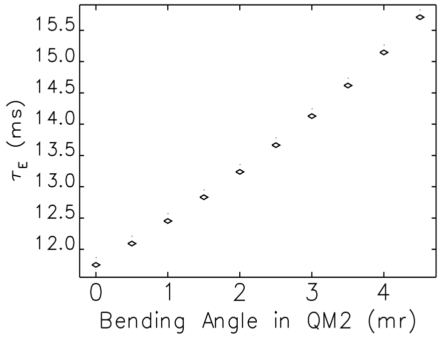

Figure 9: The longitudinal damping time versus the bending angle.

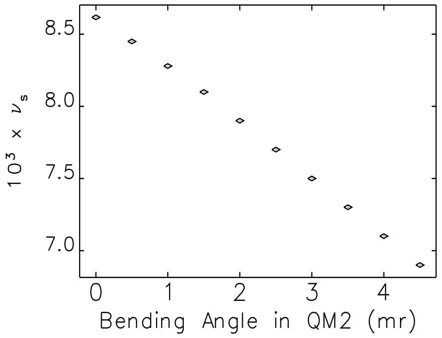

Figure 10: The longitudinal tune versus the bending angle.

CONCLUSION

We have studied two approaches to reduce the NSLS-II emittance. One is to install more damping wigglers; the other is to manipulate the damping partition. Both methods reduces the emittance effectively; however the latter method saves straights for the users, and consumes less rf power.

REFERENCES

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[2] S.C.Leeman, et al., Phys. Rev. ST Accel. Beams 12, 120701 (2009).