NSLS-II LATTICE OPTIMIZATION WITH DAMPING WIGGLERS*

W. Guo#, S. Kramer, S. Krinsky, Y. Li, B. Nash, T. Tanabe

BNL, Upton, NY 11973

Abstract

NSLS-II, the third-generation light source which will be built at BNL is designed and optimized for 3 GeV energy, ultra-small emittance and high intensity of 500 mA. It will provide very bright synchrotron radiation over a large spectral range from IR to hard X-rays. Damping wigglers (DWs) are deployed to reduce the emittance of 2 nm by factors of 2-4, as well as for intense radiation sources for users. The linear and nonlinear effects induced by the DWs are integrated into the lattice design. In this paper, we discuss the linear and nonlinear optimization with DWs, and present a solution satisfying the injection and lifetime requirements. Our approach could be applied to the other light sources with strong insertion devices.

LINEAR INTEGRATION OF THE DWS

The discussion of optical compensation of insertion devices dates back to the design of early third-generation light sources two decades ago [1]. Most light sources apply a global correction method to restore the beta function and phase advance at the sextupoles [2,3]. In contrast to the global correction method, compensation in the same straight was discussed in Ref. [4], which would require a minimum of four quadrupole families for complete compensation around the ID. Attempt was made in Ref. [5] to restore the global symmetry including the sextupoles.

Modern third-generation light sources usually deploy a large number of harmonic sextupoles to correct the nonlinearity. The sextupoles are normally optimized in one period. The optimization is related to the beta function and phase advance. When the IDs are added, a straightforward approach would be to correct the beta function and phase advance at the sextupoles assuring the optimization is still valid. This is the basis of the global compensation.

We would like to point out that the global correction method cannot completely restore the beta function and phase advance at all places in the ring. As a matter of fact, there is always residual beta beat around the ID. Further more, usually only those quadrupoles around the insertion device have large strength change if the global correction converges. This is obvious if one bears in mind that any beta beat caused by one quadrupole cannot be completely eliminated by the other quadrupoles. The residual peak beta beat is typically a few percent, depending on the focusing strength of the ID. The quadrupole strength changes are of the same level. Therefore the local sextupoles would see different beta functions. The linear chromaticity would also change due to the quadrupole variation. In other words, the symmetry is not perfectly restored, especially for strong IDs.

The NSLS-II baseline will install three DWs in the 15-fold symmetric lattice. The DWs cause about 10% peak beta beat in the vertical plane if not corrected. We are considering various approaches to integrate the DWs. The global compensation technique has been discussed in Ref. [6]. In this paper we examine the local correction approach. There are three quadrupole families on each side of the straight sections. Local compensation imposes four constraints: symmetry (α_x=0 and α_y=0) and phase advance ($\Delta\mu_x$=0 and $\Delta\mu_y$=0). With three knobs one can only satisfy α_x=α_y=0 and correct phase advance in one plane. The quadrupoles in the nonzero dispersion region can't be used for this purpose because of the stringent chromatic requirement. One idea is to use two adjacent straights to restore symmetry and tunes. However, in either case the beta functions are different for the local sextupoles.

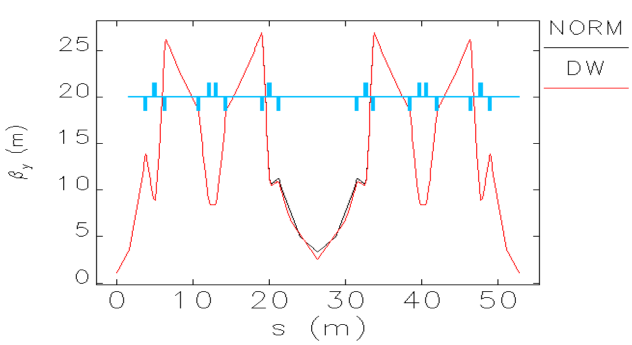


Figure 1: The comparison of the vertical beta functions of a normal cell and a DW cell. The quadrupoles are also shown. We see that the change in vertical beta function is small and localized.

At NSLS-II the DWs are designed not to vary the gap, which makes it convenient to treat them as lattice elements. Since there is no way to restore the full 15-fold symmetry with 3 DWs, we consider a 3-fold lattice from the beginning. We use the three quadrupole families in the DW straight to restore the symmetry (α_x=0 and α_y=0), and to correct the phase advance in the horizontal plane

*Work supported by U.S. DOE, Contract No. DE-AC02-98CH10886
#wguo@bnl.gov

($\Delta\mu_x$=0). Note the horizontal off-momentum closed orbit and beta function are also matched to the next leading order with corrected μ_x. The off-momentum optics in the vertical plane is acceptable even though μ_y is not restored. The vertical beta function for cells with and without DW are compared in Fig. 1. Although not presented here, we find the horizontal beta function is almost perfectly corrected. The sextupoles are optimized based on the linear optics with DWs.

SEXTUPOLE OPTIMIZATION

We use a kick map to model the DWs [8]. For simulation we use Elegant, and most of the functions mentioned here were implemented into Elegant [9]. The dynamic aperture is optimized using the approach proposed in Ref. [10]. The penalty function is a weighted sum of the resonance terms, the tune shift with amplitude, and the linear and nonlinear chromaticity.

In the baseline lattice of NSLS-II there are only two chromatic sextupole families (3 magnets) in each cell, which are used for the linear chromaticity correction. Recently we found the dynamic aperture is limited by the 2nd order chromaticity [7]. To add one more knob with good sensitivity, we consider shifting the position of one of the chromatic sextupoles towards the higher dispersion region, as illustrated in Fig. 2. With three chromatic knobs we were able to control both first-order and second-order chromaticity. The tune shift versus momentum is shown in Fig. 3, and the tune excursion in plotted in Fig. 4 with resonance lines. One can see from Fig. 4 that there is no crossing of imperfection resonance up to order 4 for $|\delta|\leq 2.5\%$.

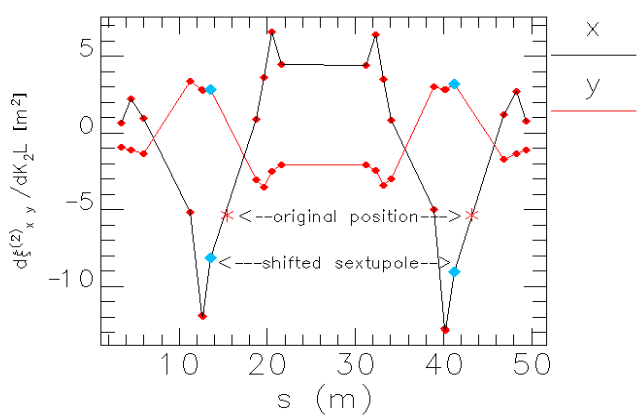


Figure 2: Sensitivity of the 2nd order chromaticity per unit of sextupole strength change (ΔK_2L). The diamonds represent sextupoles.

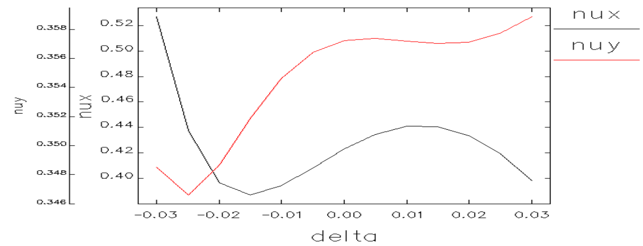


Figure 3 : Tune change versus momentum.

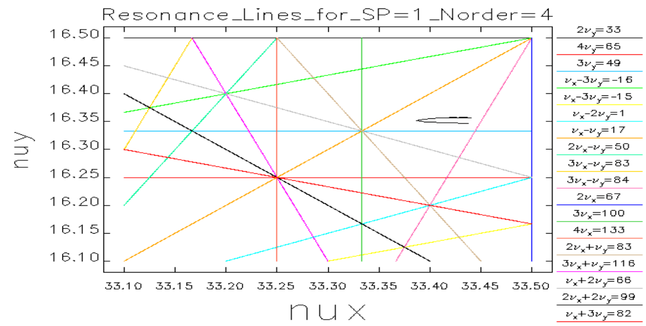


Figure 4: The tune excursion for $|\delta|\leq 2.5\%$ (black curve in the upper right corner) is contained in the stable region.

The working point for this case is (33.42,16.36). The sextupoles are optimized in one-third of the ring. The chromatic sextupoles have family correlation in all 15 cells to provide periodic focusing for the off-momentum particles. The geometric sextupoles were also correlated in families, except those in the DW super cell.

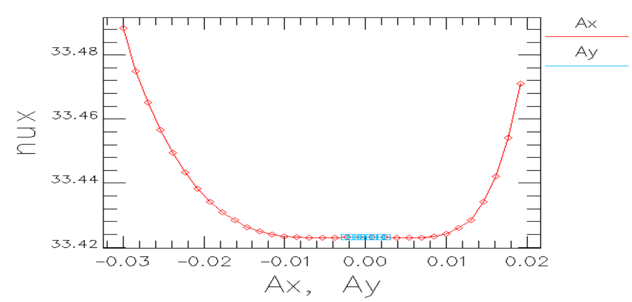


Figure 5: The horizontal tune shift with amplitude.

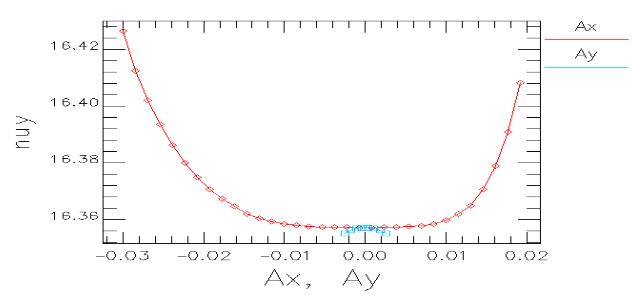
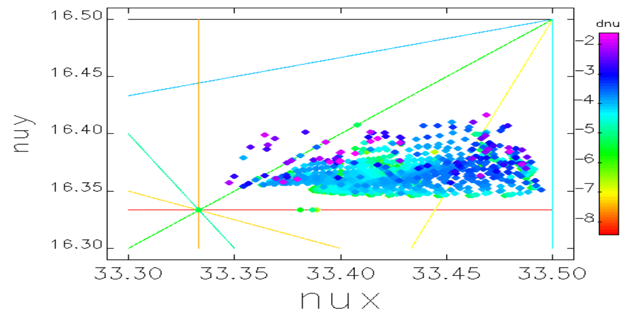


Figure 6: The vertical tune shift with amplitude.

The tune shift with amplitude is shown in Fig. 5 and 6. Note the tune shift is less than 0.02 for x<15mm and y<4mm. Therefore the tunes do not move too far away from the black curve shown in Fig. 4. This ensures particles stay in the stable region in presence of the required momentum and transverse offsets.



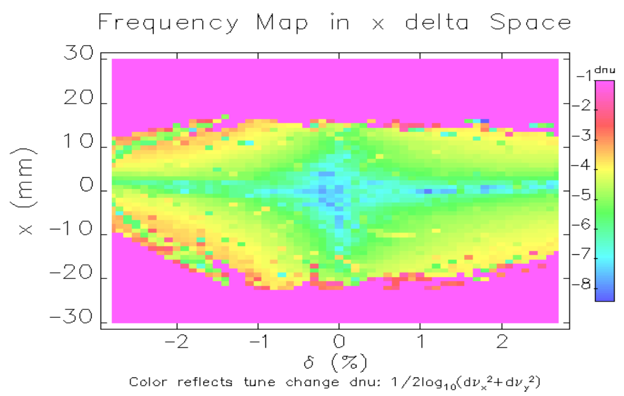
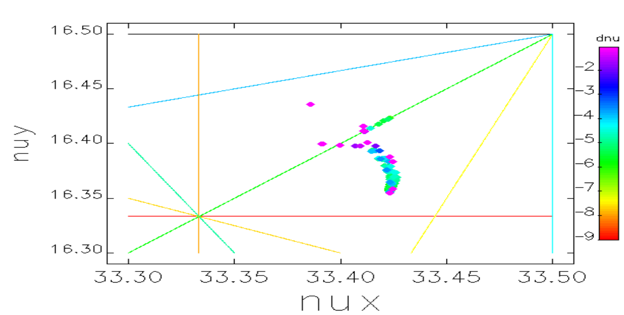


Figure 7: Diffusion weighted frequency map in (x,δ) space.

This is verified in the frequency maps shown in Fig. 7 and 8. In both cases, the magnet misalignment errors and multipole errors are added according to the NSLS-II specifications. There is no strong resonance structure in these two frequency maps for |x|<15 mm, which is the required dynamic aperture for injection. Touschek scattering simulation with rf (3.1 MV), horizontal aperture, and radiation damping gives about ±2.5% momentum aperture and 5 hours Touschek lifetime.



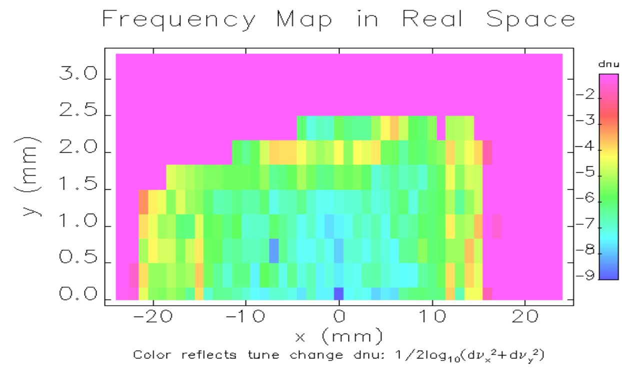


Figure 8: Diffusion weighted frequency map in (x,y) space.

CONCLUSION

We have discussed an approach to dynamic aperture optimization for NSLS-II with damping wigglers. We found DWs cause mostly linear effects. A local linear correction scheme was applied to integrate the DWs and sextupoles were optimized based on the corrected lattice. With a third chromatic sextupole obtained by moving one of the existing sextupoles, we were able to minimize the tune excursion with momentum and transverse oscillation amplitude. The lattice considered here has sufficient dynamic aperture for injection and meets the requirement on the Touschek lifetime.

REFERENCES

[1] A. Jackson, et. al., PAC'89, p1752-1754 (1989).
[2] B. Singh, et. al., PAC'07, p1118-1120 (2007).
[3] M. Belgroune, et. al., ,EPAC'06, p3407-3409 (2006).
[4] J. Corbett, et. al., PAC'99, p2358-2360 (1999).
[5] J. Bengtsson and E. Forest, AIP Conf. Proc. 255, 229-233 (1991).
[6] T. Shaftan, EPAC'06, p3490 (2006).
[7] NSLS-II design report, p627: http://www.bnl.gov/nsls2/project/cdr/ch_06_lattice_accelerator_physics.pdf; and J. Bengtsson, "Control of Dynamic Aperture," BNL-81770-2008-IR.
[8] P. Elleaume, EPAC'92, p661 (1992).
[9] M. Borland, Advanced Photon Source LS-287, 2000, and http://www.aps.anl.gov/Accelerator_Systems_Division/Operations_Analysis/manuals/elegant_latest/elegant.html.
[10] J. Bengtsson, "The Sextupole Scheme for the Swiss Light Source(SLS): An Analytic Approach, " SLS Note 9/97.