

# NLSL-II LATTICE OPTIMIZATION WITH NON-ZERO CHROMATICITY\*

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## Abstract

Chromaticity is usually set to non-zero value at the third generation light sources to cure the intensity induced instabilities. It is effective in suppressing the beam centroid oscillation; however, it is repeatedly reported that the beam lifetime decreases significantly when chromaticity goes up. This is probably due to the crossing of resonance lines by the enlarged tune footprint. In this paper we optimize the NLSL-II lattice at different positive chromaticity settings. The tune footprint is adjusted to fit in the stable region divided by the strong resonance lines. Tracking results show that we can maintain a lifetime similar to that of the zero-chromaticity lattice solutions.

## INTRODUCTION

NLSL-II is a third-generation light source under construction at the Brookhaven National Laboratory. The storage ring is comprised of 30 double-bend-achromatic (DBA) cells and has 15 superperiods. The alternative long and short straights have lengths 9.3 m (high  $\beta_x$  and low  $\beta_y$ ) and 6.6 m (low  $\beta_x$  and  $\beta_y$ ), 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 major accelerator components, such as the magnets and vacuum chambers, are already in the production phase and commissioning is scheduled to start in April 2013.

The installation of the three DWs reduces the 15-fold symmetry to 3-fold. Our strategy to maintain the dynamic aperture is to integrate the DWs as accelerator components. Particularly the horizontal tune and the mirror symmetry about the center of the straight ( $\alpha_x = 0$  and  $\alpha_y = 0$ ) are restored using the three quadrupole families in the straight matching section. The sextupole optimization is carried out in one-third of the ring, and we have been successful in finding solutions with sufficient dynamic aperture ( $x = 15\text{mm}$ ) for injection, and 2.5% momentum dynamic aperture [1].

We use the analytical method proposed in [2] to optimize the sextupoles. A script based on the simulation code Elegant [3] is used to minimize the nonlinear terms generated by sextupoles and to adjust the tune footprint. The solutions are tested by tracking with misalignment and magnetic field errors, as well as insertion devices. Frequency

map and momentum aperture are examined to avoid resonance structure and particle loss inside the required aperture.

## NONLINEAR OPTIMIZATION APPROACH

The optimization starts from the linear solution. One-third of the ring (10 DBA cells) is constructed from the basic module—two DBA cells with a long and a short straight. Then the damping wiggler is added to one of the long straights, and the quadrupoles are tuned to restore the symmetry and the horizontal tune. A typical solution is shown in Fig. 1. A grid of such linear solutions were found in the interesting tune window, which is  $(33 \pm 0.5, 16 \pm 0.5)$ , in our case.

In this paper we discuss two solutions. The one shown in Fig. 1 is with tunes  $(33.148, 16.270)$  and chromaticity  $(+2, +2)$ . Another solution has a similar linear lattice, except the working point is slightly adjusted to  $(33.166, 16.271)$ , and the chromaticity is set to  $(+5, +5)$ . A typical solution with chromaticity  $(0, 0)$  can be found in [1]. We start from a working point that is at the center of a stable

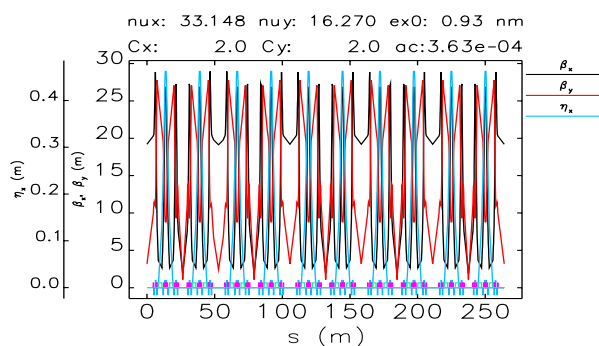


Figure 1: One-third of the lattice is used for sextupole optimization. The damping wiggler is integrated in the second long straight (around  $s = 52$  m).

region bounded by the strong resonance lines. From our experience, the most dangerous resonances are respectively: first order:  $\nu_x, \nu_y$ ; second order:  $2\nu_x, 2\nu_y, \nu_x \pm \nu_y$ ; and third order:  $3\nu_x, \nu_x \pm 2\nu_y$ . Because the limiting aperture is usually in the vertical plane imposed by the insertion devices, we find in many cases the linear coupling resonance defines (part of) the boundary of the dynamic aperture. It is well known that when the linear motion is perturbed by the linear coupling resonance ( $\nu_x \pm \nu_y = \text{integer}$ ), the action ( $J_x$  or  $J_y$ ) will oscillate; however, the sum  $J_x + J_y$  is a constant. The period of the oscillation is related to the

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separation from the resonance and the resonance strength. And the particle is usually lost in less than a few hundreds of turns when  $J_y$  grows.

It is relatively simple to achieve a 15 ~ 30 mm aperture for the on-momentum optimization, as long as the resonance terms and the amplitude dependence are minimized. The tune excursion can be made as small as 0.05 in both planes; therefore, in most cases the tune footprint will not cross the strong resonance lines listed above. In this case the motion is limited by the physical aperture, or by the higher order resonances.

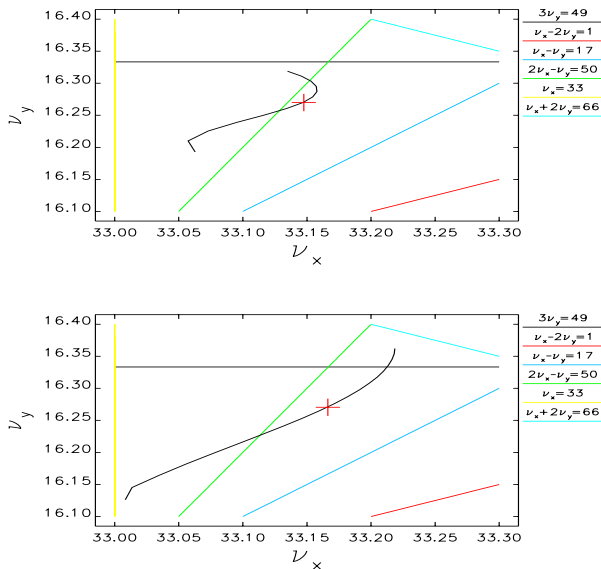


Figure 2: The tune excursion when  $dp/p$  varies from  $-2.5\%$  to  $+2.5\%$ . Resonance lines are shown up to third order. Upper plot is for the working point (33.148,16.270) with (+2,+2) chromaticity, and the lower plot is for (33.166,16.271) with (+4.6,+4.6) chromaticity.

The difficulty is the off-momentum aperture. The tune excursions for the two example solutions are plotted in Fig. 2. It is hard to minimize the tune excursion when chromaticity is nonzero and  $\delta$  varies from  $-2.5$  to  $2.5\%$ ; however, one can adjust the linear and nonlinear chromaticity to avoid the strong resonance lines. In Fig. 2, the tune crosses a weak skew sextupole resonance line  $2\nu_x - \nu_y = 50$  for both cases and  $3\nu_y = 49$  for the second solution, but tracking with error shows that this is not a problem. The working point needs to be adjusted in case a satisfactory solution cannot be found by varying the sextupoles. In that situation a nearby working point would be taken from the grid of solutions.

The misalignment and magnetic field errors are then added before tracking for apertures. The NSLS-II misalignment specification is as follows: girder to girder, 100  $\mu\text{m}$ ; magnet to magnet on the same girder, 30  $\mu\text{m}$ ; girder roll, 0.5 mr; magnet roll with respect to girder, 0.2 mr.  $5 \times 10^{-4}$  quadrupole field strength error and  $1 \times 10^{-3}$

sextupole strength error, together with the multipole errors, are also included for each magnet. Afterward the closed orbit is corrected using beam-based-alignment algorithm. The two steering magnets at the ends of each girder are set such that the closed orbits are steered as close as possible to the center of all the magnets. The residual offset of the quadrupole and sextupole magnets is about 20  $\mu\text{m}$  (rms) after the orbit correction. A few percent beta-beat is generated by these errors, so all the quadrupoles were adjusted to correct the beta-beat to  $\leq 0.5\%$ .

Fig. 3 shows a typical result of the momentum aperture. The lattice has included three DWs and three in-vacuum undulators. The parameters used in the Touschek lifetime calculation are:  $\sigma_z=4.86$  mm,  $\sigma_\delta=8.3 \times 10^{-4}$ ,  $\epsilon_x=0.85$  nm,  $\epsilon_y=8.5$  pm, and charge per bunch is 1.3 nC. The Touschek lifetime is calculated to be  $\sim 5$  hours for the two solutions. This is similar to what we found for the solutions with zero chromaticity, and it exceeds the required lifetime of 3 hours.

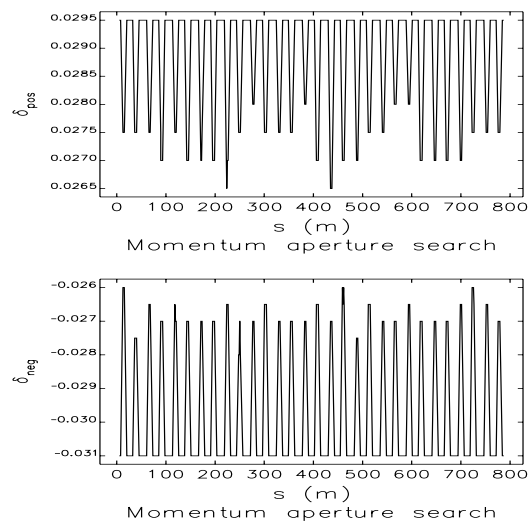


Figure 3: A typical result of the momentum aperture along the ring. The radiation damping was turned on. The rf parameters are:  $V_{rf}=3.2$  MV,  $\phi_s = 166.7^\circ$ , and  $h_{rf} = 1320$ .

## FREQUENCY MAP COMPARISON

Frequency maps for the two examples can be found in Fig. 4, 5, 6, 7.

## CONCLUSION AND FUTURE DEVELOPMENT

Lattice solutions with positive chromaticity were found. Frequency maps were compared for two chromaticity settings: (+2,+2) and (+4.6,+4.6). By carefully avoiding the strong resonance lines, similar lifetime could be achieved as compared to the solutions with zero chromaticity. Our optimization approach involves a lot of manual tuning

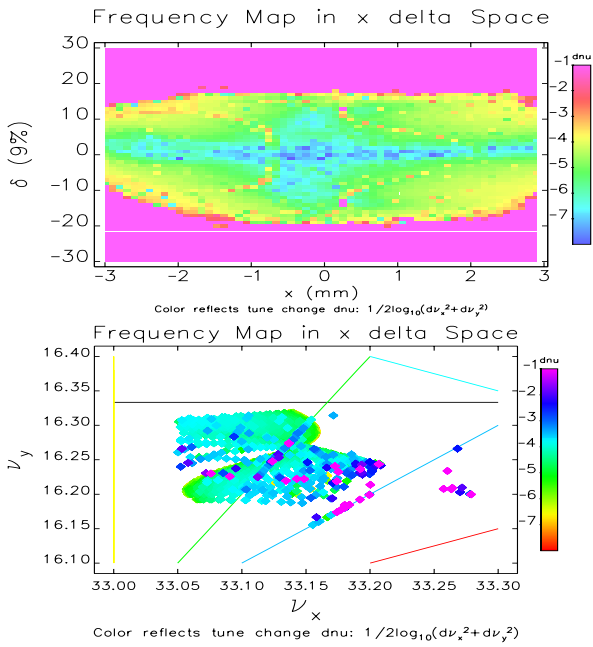


Figure 4: The frequency map in (x,p) space for the solution with (+2,+2) chromaticity.

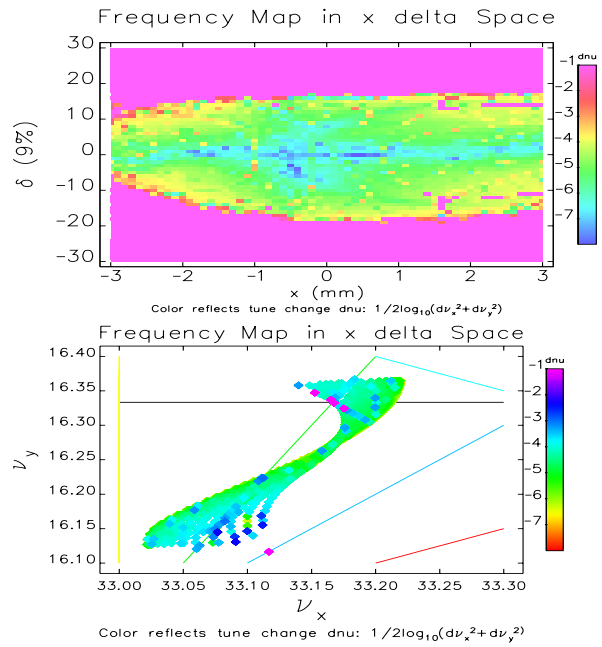


Figure 6: The frequency map in (x,p) space for the solution with (+4.6,+4.6) chromaticity.

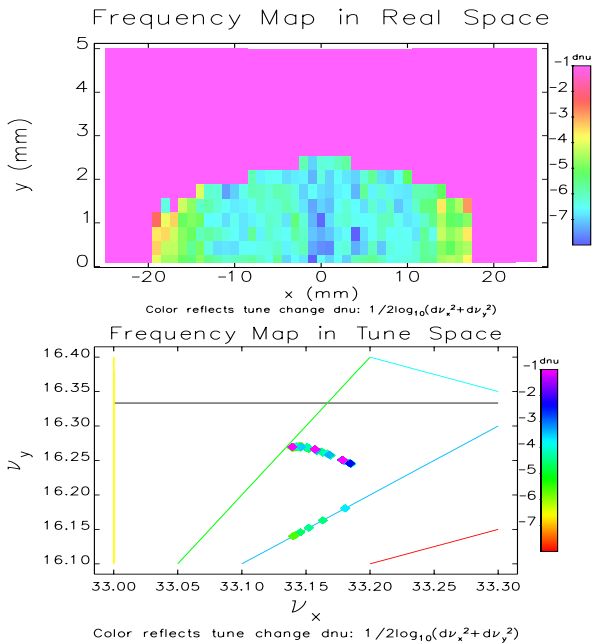


Figure 5: The frequency map in (x,y) space for the solution with (+2,+2) chromaticity.

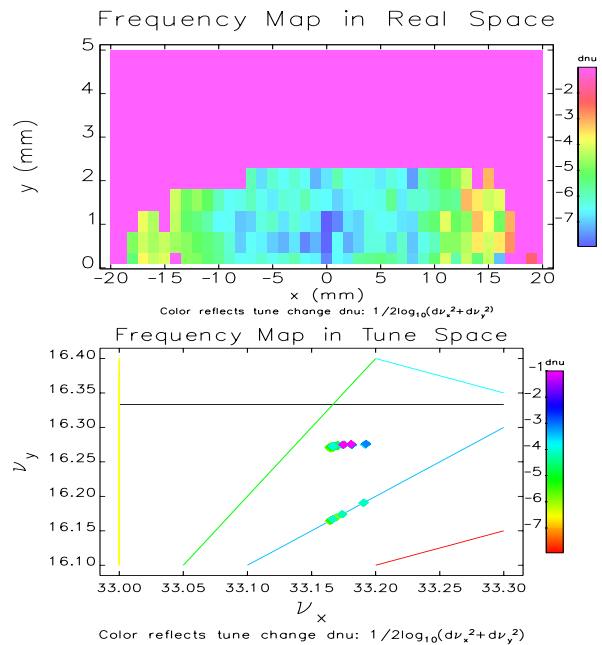


Figure 7: The frequency map in (x,y) space for the solution with (+4.6,+4.6) chromaticity.

based on experience. It would be more straightforward and less time consuming if one could develop a universal optimization method, such as the combination of the genetic dynamic aperture optimization with the resonance term minimization, and vary the working point and sextupole settings simultaneously.

## REFERENCES

- [1] W. Guo, et al., "NSLS-II Lattice Optimization with Damping Wigglers," Pac09.
- [2] J. Bengtsson, "The Sextupole Scheme for the Swiss Light Source (SLS): An Analytic Approach," SLS Note 9/97.
- [3] M. Borland, Advanced Photon Source LS-287, 2000.