

CONSIDERATION OF A DOUBLE BEND ACHROMATIC LATTICE FOR NSLS-II *

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Abstract

We discuss the Double Bend Achromatic (DBA) lattice as a possible choice for the NSLS-II storage ring. The DBA possesses a large number of straight sections with easily tunable beta functions which can be used for insertion device sources and for damping wigglers to reduce emittance. The dispersive regions can be designed to minimize the strength of the chromatic correction sextupoles. A key constraint is the imposition of a limit on circumference which is closely tied to cost. We discuss optimization of the dynamic aperture by minimizing the non-linear driving terms using high-order achromatic cancellation in the non-linear lattice.

INTRODUCTION

In the design of the 3 GeV storage ring for NSLS-II, we wish to provide: (1) ultra-low emittance (<1 nm); (2) low-beta straights for small-gap (5 mm) in-vacuum undulators; (3) straights with higher β_x to be used for top-off injection as well as insertion devices--all the injection kickers and septum in same straight; (4) adequate dynamic aperture for top-off injection; and (5) sufficient energy acceptance ($\geq 3\%$) to assure Touschek lifetime >1.5 hours. In this note we discuss the use of a DBA lattice to meet these goals. Use of a TBA lattice is discussed elsewhere[1].

LINEAR LATTICE DESIGN

A major challenge is to achieve a robust lattice with adequate dynamic aperture. While imposing a circumference limit of 800m, it is difficult to achieve an emittance below 1nm in the absence of insertion devices. However, with zero-dispersion straights, the radiation emitted by the IDs reduces the emittance. Therefore, by using damping wigglers, we achieve the desired very small emittance without introducing unacceptably large lattice nonlinearity. Fig. 1 shows the lattice function for the DBA(15x2) lattice proposed for NSLS-II.

The minimum emittance for a double bend achromatic (DBA) lattice with 2M dipole magnets and electron energy γmc^2 is given by

$$\varepsilon_0^{\min} = (7.7 \times 10^{-4} \text{ nm-rad}) \gamma^2 / M^3. \quad (1)$$

The achievable emittance for a realistic lattice design is about twice this minimum value. The momentum compaction is

$$\alpha = \frac{\pi^2}{6M^2} \frac{2\pi \rho_0}{C}, \quad (2)$$

where ρ_0 is the dipole magnet bending radius and C is the ring circumference. Note that the momentum compaction increases linearly with bend radius.

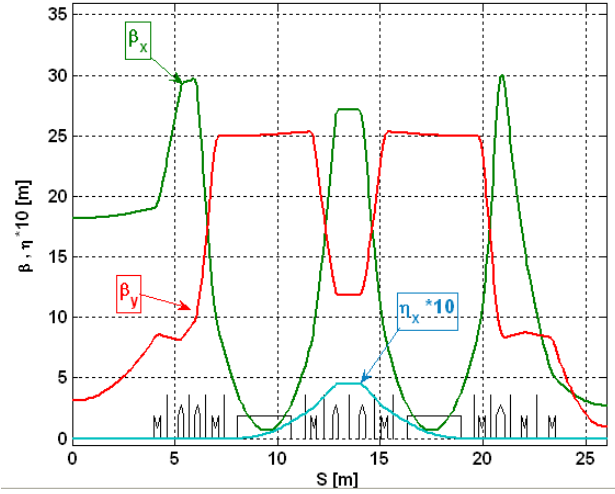


Fig. 1 The lattice functions for one DBA cell. A superperiod is comprised of this cell plus its reflection about the insertion center.

The emittance ε_w with damping wigglers is related to that without damping wigglers ε_0 by $\varepsilon_w \cong \varepsilon_0 / (1 + u_w / u_0)$, where u_w / u_0 is the ratio of the energy lost per turn in the wigglers to that lost in the dipoles[2]. In NSLS-II, we choose to have a large dipole bending radius. This reduces the energy radiated in the dipoles, which means we need to radiate less energy in the wigglers to reduce the emittance by a given factor.

To be more precise, consider a wiggler of length L_w having bending radius ρ_w centered in the insertion. The ratio of the fractional energy spread with the wiggler to that without is

$$\frac{\delta_w}{\delta_0} = \sqrt{\left[1 + \frac{L_w}{2\pi \rho_0} \frac{4}{3\pi} \left(\frac{\rho_0}{\rho_w}\right)^3\right] \left[1 + \frac{L_w}{4\pi \rho_0} \left(\frac{\rho_0}{\rho_w}\right)^2\right]^{-1}} \quad (3)$$

and the ratio of the emittance with the wiggler to that without is

$$\frac{\varepsilon_w}{\varepsilon_0} = \frac{1 + f}{1 + \frac{L_w}{4\pi \rho_0} \left(\frac{\rho_0}{\rho_w}\right)^2}. \quad (4)$$

The fluctuation factor is given by

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$$f = \frac{2C_q \gamma^2}{3\pi^2 \epsilon_0} \frac{L_w \rho_0}{\rho_w^3} \left[\frac{K_w^2 \langle \beta_x \rangle}{5\gamma^2} + \frac{\eta_0^2}{\beta_{x0}} + \beta_{x0} \eta_1^2 \right], \quad (5)$$

where $C_q = 3.84 \times 10^{-13} \text{ m}$. The horizontal betafunction is given by $\beta_x(s) = \beta_{x0} + s^2 / \beta_{x0}$, where $s = 0$ is the center of the wiggler and insertion, and $\langle \beta_x \rangle$ denotes the average value of β_x in the wiggler. We suppose the dispersion function in the wiggler has the form $\eta(s) = \eta_w(s) + \eta_0 + \eta_1 s$, where $\eta_w(s)$ is the sinusoidal dispersion generated by the wiggler itself, and $\eta_0 + \eta_1 s$ is the dispersion generated by errors elsewhere in the ring. Eq. (5) can be used to determine a tolerance on the dispersion in the insertions arising from errors.

Table 1. Basic Lattice Parameters

Energy (GeV)	3
Circumference (m)	780.3
DBA Cells	30
Bending Radius (m)	25.019
RF Frequency (MHz)	500
Momentum Compaction	3.68×10^{-4}
Tune ν_x / ν_y	32.35/16.28
Chromaticity Uncorrected ξ_x / ξ_y	-100/-41.8
Maximum Dispersion (m)	0.45
High-Beta 8m-Straights β_x / β_y (m)	18/3.1
Low-Beta 5m-Straights β_x / β_y (m)	2.7/0.95

Table 2. Lattice properties without and with 48m of 1.8T damping wigglers included.

	No DW's	48m DW's
Energy Loss (KeV)	287	1172
RF Voltage (MV)	2.5	3.7
Synchrotron Tune	0.0079	0.0094
Emittance ϵ_x / ϵ_y (nm)	2.1/0.008	0.56/0.008
Damping Time τ_x / τ_s	54/27 (ms)	13/6.5 (ms)
Energy Spread (%)	0.05	0.098
Bunch Duration (ps)	10	15

Table 3. Parameters of some IDs considered for NSLS-II

	Length (m)	Period (mm)	Field (T)
Damping Wiggler	6	100	1.8
In-vacuum Undulator	3	19	1
Superconducting Undulator	2	14	1.4
Superconducting Wiggler	0.75	15	3.5

As in the ESRF, the NSLS-II lattice has alternating high-low beta-x insertions. A large value of β_x is desired

at the injection septum. Small β_x is desired in undulators for beamlines designed to focus the radiation down to a small (1nm) spot. The vertical beta function should be small in undulators to optimize brightness. In fact, it is essential that β_y not be large in any of the insertion devices. The linear tune shift produced by an undulator or wiggler is

$$\Delta \nu_y = \frac{\langle \beta_y \rangle L_w}{8\pi \rho_w^2}. \quad (6)$$

Small β_y keeps the tune shift within acceptable bounds.

We have bounded the straight sections with quadrupole quartets in order to provide a local correction for the modification of the betatron functions and phases due to wiggler focusing.

The tune shift with amplitude due to nonlinear wiggler focusing is

$$\frac{d\nu_y}{dJ} = \frac{\pi \langle \beta_y^2 \rangle L_w}{4\lambda_w^2 \rho_w^2}. \quad (7)$$

In order to minimize the effect of the nonlinear focusing on dynamic aperture, it is essential to have small β_y in the insertion devices.

NON-LINEAR LATTICE DESIGN

The horizontal chromaticity per DBA cell is ~ 3.3 and the peak dispersion $\sim 0.45 \text{ m}$; hence, the sextupoles for chromatic correction are moderately strong. Our goal is to develop a conservative design for a high performance lattice which will allow straightforward commissioning and provide some leeway for enhancing performance over the life span of the facility. We wish to provide a dynamic aperture that is robust against engineering tolerances, with comfortable horizontal acceptance for top-off injection, and adequate momentum acceptance for Touschek life time. Our strategy is to implement a higher order achromat [4] by introducing 3 chromatic sextupole families in the dispersive region and 4+4 geometric sextupole families in the matching regions; i.e. a total of 11 families. The former provides full control of linear chromaticity (2 terms) and partial control of the second order (2 terms). The latter provide partial control of the first- and second order sextupolar modes (13 terms) and amplitude dependent tune shifts (3 terms). Moreover, the phase advance for a superperiod is optimized by a tune scan, i.e. the driving terms are minimized over a range of phase advances for the bare lattice by adjusting the quadrupoles in the matching sections and the dynamic aperture is evaluated by tracking.

A summary is given by Figs 2-5:

- Fig. 2 shows a tune scan of the normalized dynamic aperture (by $\sqrt{\beta_x \beta_y}$) for a superperiod;
- Fig. 3 shows the dynamic- and momentum aperture for the bare lattice, without errors;

- Fig. 4 shows the frequency map [5], i.e. amplitude dependent tune shift and diffusion map*, for on-energy particles;
- and Fig. 5 the impact of $\pm 100 \mu\text{m}$ mechanical misalignments of the quadrupoles after orbit correction.

Control of the impact of insertion devices is summarized in [6]. Work in progress includes:

- evaluation of sextupole misalignment tolerances with girders;
- control of linear coupling, vertical dispersion, and vertical emittance;
- evaluation of beam based alignment for quadrupole- and sextupole centering;
- and control of linear optics by beam response matrix measurements.

Moreover, there is also an effort to quantify the effect of the desired $\pm 2.5 \text{ mm}$ vertical mechanical aperture for the mini-gap undulators on the Touschek life time.

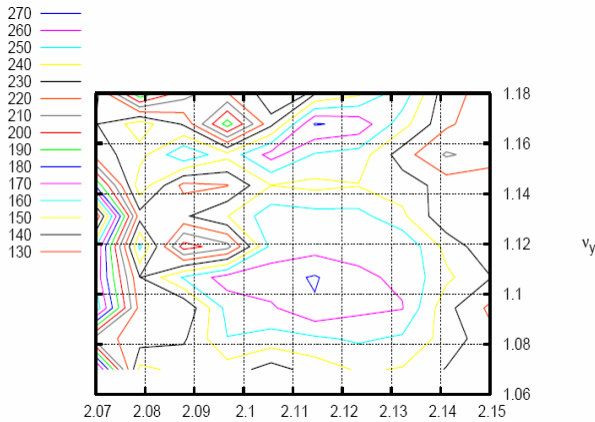


Fig. 2. Tune scan showing level curves of normalized dynamic aperture. Axes are horizontal and vertical ring tunes divided by 15. Result shows a broad flat region.

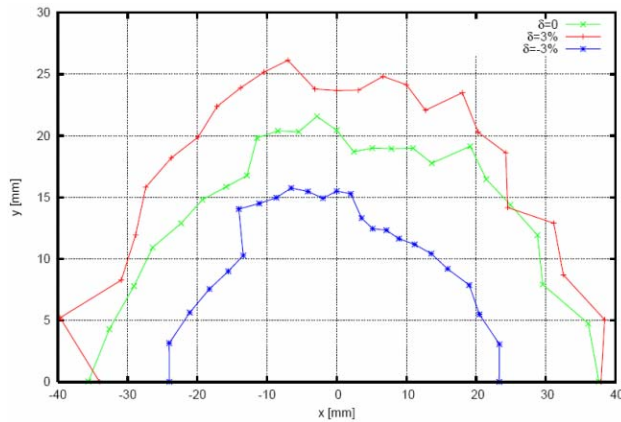


Fig. 3. Dynamic aperture for particles with $\Delta p / p = -3\%$ (blue), 0% (green), and 3% red.

$$* D = \log_{10} \left(\sqrt{(\Delta v_x)^2 + (\Delta v_y)^2} \right)$$

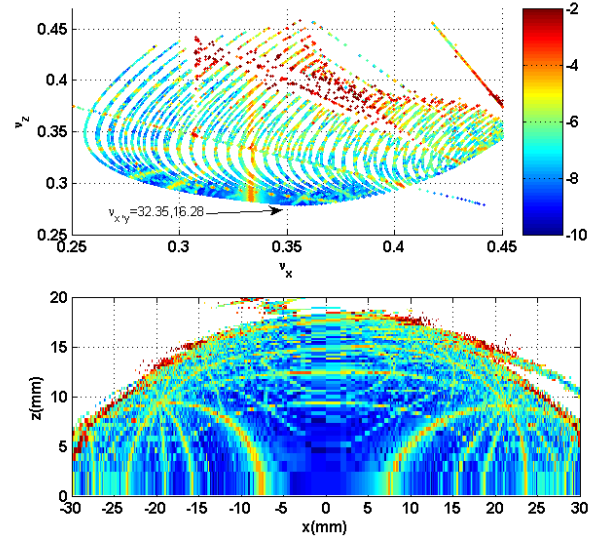


Fig. 4. Frequency map for on-energy particles.

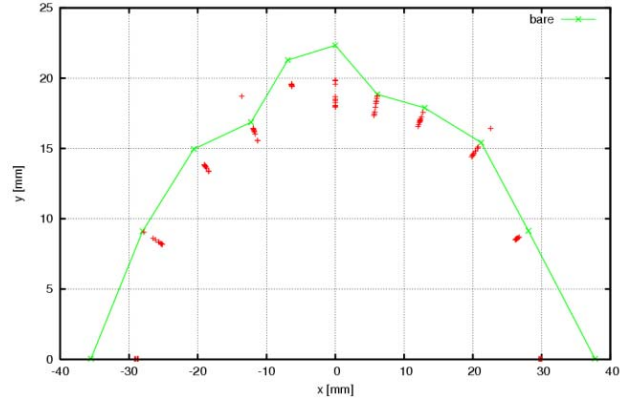


Fig. 5. Reduction of dynamic aperture due to errors.

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