OPTIMIZING THE DYNAMIC APERTURE FOR TRIPLE BEND ACHROMATIC LATTICES*

S.L. Kramer# and J. Bengtsson
BNL/NSLS, Upton, NY 11973, U.S.A.

Abstract

The Triple Bend Achromatic (TBA) lattice has the potential for lower natural emittance per period than the Double Bend Achromatic (DBA) lattice for high brightness light sources. However, the DBA has been chosen for 3rd generation light sources more often due to the higher number of undulator straight section available for a comparable emittance. The TBA has considerable flexibility in linear optics tuning while maintaining this emittance advantage. We have used the tune and chromaticity flexibility of a TBA lattice to minimize the lowest order nonlinearities to implement a 3rd order achromatic tune, while maintaining a constant emittance. This frees the geometric sextupoles to counter the higher order nonlinearities. This procedure is being used to improve the nonlinear dynamics of the TBA as a proposed lattice for NSLS-II facility. The flexibility of the TBA lattice will also provide for future upgrade capabilities of the beam parameters.

INTRODUCTION

The lattice structures being studied for NSLS-II are Three Bend Achromatic (TBA) and Double Bend Achromatic (DBA) lattices. The storage ring requirements to meet the users goals are:

Ultra-low horizontal emittance < 1.5nm (achromatic),
Diffraction limited vertical emittance at 12KeV,
Stored currents to 500mA,
At least 21 ID straight section for >5m undulators,
Top-off injection, and
A future upgrade potential to an ERL and higher energy Xrays from super bend dipoles.

The 24 period TBA lattice meets all these requirements and will be discussed here. Several properties of the TBA lattice have been expanded in order to allow optimization of the Dynamic Aperture (DA). We present the results of this optimization process, which uses the flexibility of the TBA lattice structure quite extensively.

LINEAR LATTICE DESIGN

The TBA lattice composed of iso-magnet dipoles and with θ_p total bend angle per period, could have a minimum emittance [1] given by

$$\varepsilon_{METBA} = \frac{C_q \gamma^2}{4\sqrt{15}} \frac{\theta_p^3}{J_x (3.44)^3} \qquad (1)$$

where γ is the relativistic energy, J_x is the horizontal partition factor and $C_q = 3.84*10^{-13}$m. At 3GeV a N_p=24 period ring has $\varepsilon_{METBA} \approx 0.38nm$ or a factor of more than 4 times less than the desired emittance, a comfortable design factor. The DBA lattice, having a factor of 5 greater emittance per period [1] would require $\geq$32 periods to achieve the emittance goal.

ε_{METBA} requires a ratio of the inner to outer bend angles of $\theta_i = \sqrt[3]{3}\,\theta_o$ [1] and a large phase advance between the dipoles yielding a large linear chromaticity. Since ε_{METBA} cannot be achieved, we have chosen a simpler ratio of the bend angles of $\theta_i = 2\theta_o$. This ratio is similar to the SLS TBA lattice [2], of $\theta_i = 1.75\theta_o$. We have also reduced the number of dispersion quadrupoles from four to three families, by using gradient dipoles to provide added vertical focusing. This reduction of quadrupoles allowed space for a 4th family of chromatic sextupoles that will help tune chromatic corrections to the DA. The basic TBA 24 period lattice functions are shown in Figure (1).

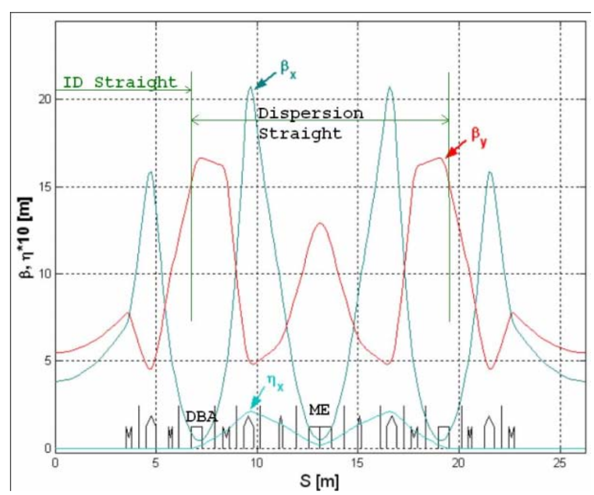

Figure 1: Lattice functions for 24 period lattice with $\varepsilon_x = 1.46nm, (\nu_x, \nu_y) = (1.562, 0.560)/cell$.

Despite attempts to increase the DA by tuning the 7 to 10(for a super periodicity=12 lattice) sextupole families, it was inadequate for injection when alignment tolerances were included. This was primarily the result of two properties of this lattice:

1) high horizontal chromaticity, $\xi_x = -3.8/cell$ and
2) small values of dispersion, $\eta_x < 0.21m$ in the chromatic sextupoles making their strength large.

Therefore we have made several changes to this basic lattice in order to counter these properties.

The outer dipoles in this lattice [DBA in Figure (1)] place serious limits on the peak dispersion values, since

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

the dispersion and its slope are given by the bend angle, θ_o and radius, ρ by:

$$\eta_x' \approx \theta_o = \frac{2\pi}{4N_p} \ and \ \eta_x \approx \frac{\rho\theta_o^2}{2}$$

at the exit of this dipole. The slope is determined by the periodicity and is equivalent to a 48 period DBA lattice. The only free parameter is the bend radius for increasing the dispersion. Also increasing the drift between this dipole and the vertically focusing quadrupole will also increase the dispersion. We have increased the bend radius for all dipoles in the lattice from $\rho = 8.4 \rightarrow 18.3m$, which increases the dipole lengths by a factor of 2.18X. Although this more than doubles the dispersion from the outer dipole the slope is fixed by the periodicity, so the peak dispersion we have achieved in our lattice study only increased by 50%, from $\eta_x = 0.21 \rightarrow 0.31m$. Future studies will reconsider the bend angle split, since a larger outer bend angle will also increase the dispersion slope.

The second change to the lattice was to split the four strong horizontally focusing quadrupole in the dispersion and ID regions into two shorter quadrupoles with independent strengths, to try to reduce their large contribution to horizontal chromaticity from these quadrupoles. The thought was that the peak beta functions could be reduced in these quads and their net contribution reduced. Although the beta's were reduced, the contribution to the chromaticity from these quadrupoles was not significantly different, however the net chromaticity was reduced by 15% by increasing the opposite sign chromaticity from the vertically focusing quadrupoles, as shown in Figure (2). Continued optimization of the linear lattice function with these extra quadrupoles, lowered the chromaticity to $\xi_x \approx -2.1/cell$. Both of these changes to the lattice increase the circumference of the ring, but will also be shown to improve the DA solution for these very nonlinear lattices. The splitting of the long quadrupole in the ID straight section also served an important improvement to the lattice, since now tune, phase and beta function modulations resulting from undulators can be locally compensated, minimizing their impact on the DA[3].

ENHANCED TBA LATTICE

The final lattice used these methods together with an increase in the natural emittance from 1.5 to 2.2nm, where we will rely on the emittance reduction of the strong undulators to meet the lower emittance goal during operations. We have also broken the 24 fold symmetry with a longer ID straight section with higher beta functions for injection, RF and lower brightness wiggler operation, i.e. super periodicity=12. Figure (3) show the beta function for one period of this Enhanced TBA lattice (ETBA). Additional features of the increased dipole bend radius are a reduction of the energy loss per turn, reduction of the natural energy spread, increased momentum compaction and a larger reduction of beam emittance with increasing undulator fields.

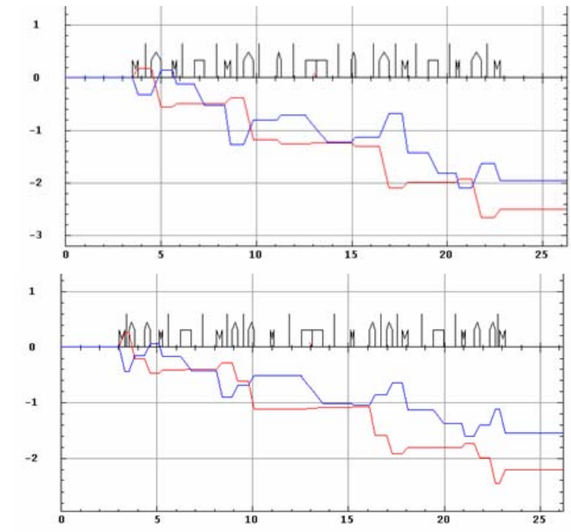

Figure 2: Cell chromaticity H(red) and V(blue) for Basic TBA (top) and split quadrupole TBA(bottom).

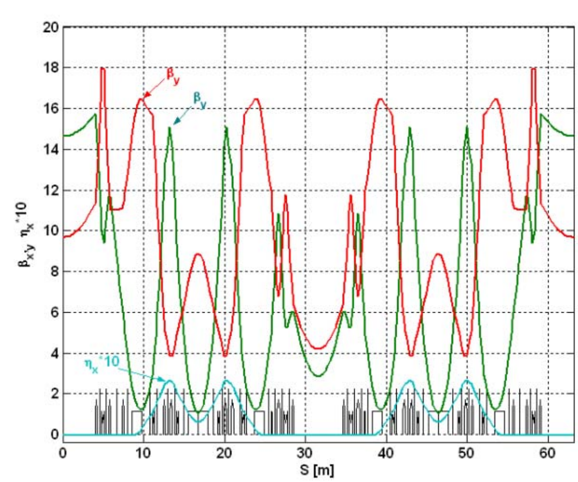

Figure 3: Beta functions for the ETBA lattice with $\varepsilon_x = 2.24nm,\ (\nu_x, \nu_y) = (1.345, 0.616)/cell,$ $(\xi_x, \xi_y) = -2.09, -1.15/cell,\ and\ C = 758m.$

WORKING POINT SEARCH WITH HIGHER ORDER OPTIMIZATION

As shown previously [4], for each lattice we perform a tune scan with optimization of the sextupole driving terms over a 4 cell period to 2nd order in the sextupole strengths. At each tune point the area of the DA is calculated and plotted as contours in the working point diagram. Broad peaks are then used to define the lattice tunes that yield maximum cancellation of these driving terms for a 3rd order achromat. In particular, the expansion used here, requires minimization of 23 terms:

- 13 geometric resonance modes,
- 3 amplitude dependent tune shift terms, and

- 7 chromatic terms.

The tune scan of the ETBA period is shown in Figure (4), with contour lines of increasing DA area. We observe a broad peak around period tunes of (2.688, 1.232). With this tune selected, it was possible to optimize the sextupoles tunes to 2nd order and find large DA with small diffusion over a horizontal aperture |X| > 20mm. The frequency map and DA for this lattice with sextupole tuned are shown in Figure (5). This DA is maintained for alignment tolerance on the quadrupoles of ~0.1mm, with correction of the resulting closed orbit distortion. The chromatic dependence of the lattice properties are well controlled to greater than 4% with the 4 chromatic sextupoles in this lattice, as shown in Figure (6).

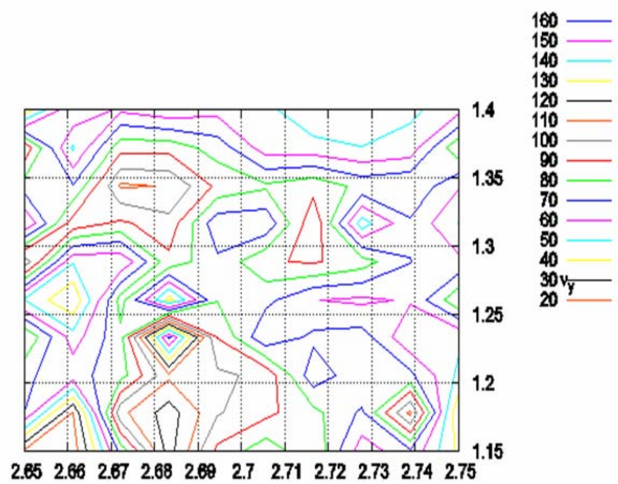

Figure 4: Tune scan for DA optimization of the ETBA lattice with 13 sextupole families. Contours show the DA area (in mm^2) as function of (ν_x, ν_y), the period tune.

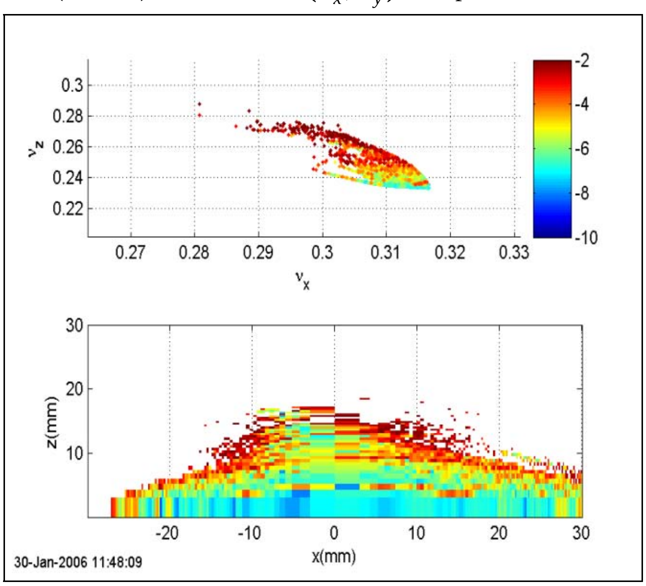

Figure 5: Frequency diffusion map (period tune) and DA for the ETBA in high beta ID straight $(\beta_x = 14.6, \beta_y = 9.7m)$.

CONCLUSIONS

We have demonstrated several techniques for reducing the non-linear behavior for low emittance TBA lattices. Most of them involved increases in the cell length, which is counter to the tendency to reduce the circumference for cost savings. However, to insure storage ring performance, especially with the very non-linear small gap and wavelength undulators being proposed, it is prudent to design a lattice with reduced non-linearity and improved DA. Despite these studies, the decision was to go with a DBA(15x2) lattice[5].

REFERENCES

[1] S.Y.Lee, Phys. Rev. E **54,** p. 1940(1996).
[2] SLS Design Handbook, (1998).
[3] T. Shaftan et al. these proceedings (2006).
[4] S.L. Kramer and J.Bengtsson, PAC05, p.3378 (2005). J. Bengtsson, PAC05, p. 1670 (2005).
[5] S.L. Kramer, et al. these proceedings (2006).

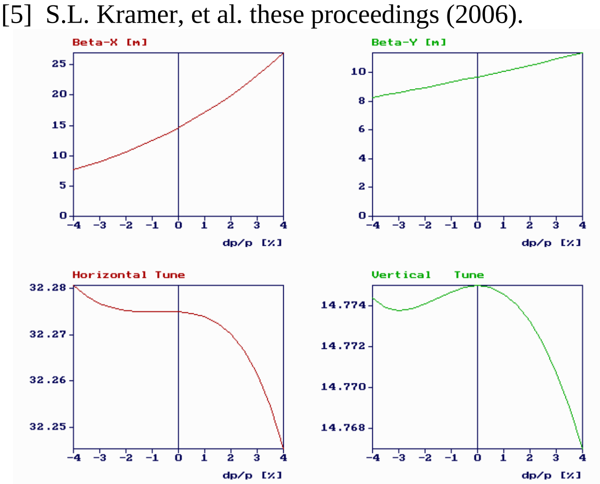

Figure 6: Chromatic behavior of the ETBA lattice.

Table I: Parameters for the two TBA lattice.

Parameter	Basic TBA(24)	ETBA(12 X 2)
Nux/cell(Total)	1.565 (37.56)	1.3448 (32.275)
Nuy/cell(Total)	0.588 (14.11)	0.6156 (14.775)
ξx/cell(Total)	-3.806 (91.4)	-2.085 (-50.03)
ξy/cell(Total)	-1.21 (29.06)	-1.145 (-27.49)
βx (m)	3.75	2.87 (14.6)
βy (m)	4.9	4.2 (9.67)
εx (nm)	1.46	2.24
ρ (m)	8.4	18.33
Lid (# - m)	24- 7	12-6 (12-8)
Circum (m)	630	758.355
α1 (*10^-4)	1.66	4.35
α2 (*10^-3)	0.65	4.00
δE/E (10^-4)	9.08	6.4
Jx	1.096	1.235
Uo (KeV)	852.6	390.78
DA (X x Y mm)	(15 x 16)	(24 x 23)
dP/P	> +/-4 %	> +/-4 %