DOUBLE TRIPLE BEND ACHROMAT FOR NEXT GENERATION 3 GeV LIGHT SOURCES

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Abstract

The Double Triple Bend Achromat (DTBA) is a newly designed cell for a next generation 3 GeV synchrotron light source. DTBA is inspired by the Double-Double Bend Achromat (DDBA) cell designed for Diamond and originates from a modification of the ESRF HMBA 6 GeV cell, combining in this way the best characteristics of each lattice. The lattice achieves a natural emittance as low as 131 pm, together with a sufficient Dynamic Aperture (DA) for injection and lifetime. Two cells are designed with different end-drift lengths providing two different Long Straight Sections (LSS) for insertion devices, 5 and 7.5 m long, in addition to a new middle-straight section of 3 m. The characteristics of the lattice together with the results on emittance, DA and Touschek lifetime are presented after extensive linear and non-linear optimisations, with and without the presence of errors and corrections.

INTRODUCTION

Inspired by the DDBA cell studied as an upgrade for the Diamond Light Source [1,2], the 3 GeV Double Triple Bend Achromat (DTBA) lattice is a result of a modification of the ESRF HMBA 6 GeV cell [3] used for the future ESRF upgrade. Profiting from the lower gradients and fields required for 3 GeV, the magnets' lengths are reduced and the central dipole of the HMBA cell is removed creating a new 3 m straight section for an insertion device (ID_B, see Fig. 1).

DTBA LAYOUT

Figure 1 presents the optics and magnets layout of the DTBA cell. It includes longitudinally varying dipoles (DL), optimised for larger dispersion at the sextupoles and minimum horizontal emittance [4]. The central dipoles (DQ) are combined function magnets that allow a -I transformation between the sextupoles, and, as a result of the larger horizontal damping partition number (J_x), they reduce the emittance. A family of octupoles is also required to adjust detuning with amplitude.

Cell-length Adaptation

Several main characteristics of the 3 GeV Diamond Light Source Upgrade (Diamond-II) have been taken into account when designing the DTBA lattice. Diamond-II will have a circumference of close to the existing 561.0 m and will consist of 24 cells placed in a 6-fold symmetry, with a superperiod composed as (-C1, C2, C2, C1). The total DTBA length has been adjusted as described in [5]. C2 is symmetric and is created ensuring the quadrupole gradients are below 70 T/m; the DQ has a smaller than 30 T/m quadrupole field and a 0.6 T dipole field. C1 is asymmetric and is obtained from C2 by adding 1.5 m to the last drift.

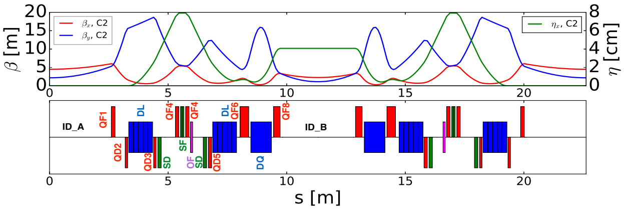

Figure 1: C2 twiss and layout; red: quadrupoles, blue: dipoles, green: sextupoles, magenta: octupoles.

C1 Design

C1 is asymmetric, with the last straight section longer by 1.5 m compared to C2. To keep the lattice symmetry, as a first approach, the total phase advance of C1 should be as close as possible to that of C2; the achromatic condition should also be preserved.

Two of the options that were considered for the C1 design have been presented in [5]. A third option, incorporating a triplet, is presented here: two quadrupoles were added at the end of C1 drift which help to successfully match the tune to the tune values of C2, and the twiss functions to $\alpha_x = 0, \alpha_y = 0, \eta'_x = 0$, and $\eta_x = 0$ (see Figure 2). The last 6 quadrupoles participate in the matching, and have practically no impact on the phase-advance between sextupoles; note, however, that this design does not produce a β_x waist in the ID_C. The characteristics of a DTBA lattice with 6 superperiods are given in Table 1 and the layout of one SP is presented in Figure 3.

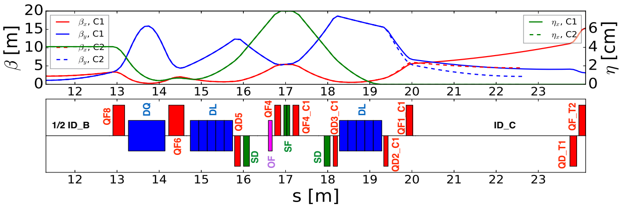

Figure 2: C1 using a triplet at the end of the cell; twiss shown from the middle until the end of the cells.

LATTICE OPTIMISATIONS

Heavy computational linear and non-linear optics optimisations were performed using Elegant [6], Accelerator Toolbox (AT) [7] and Multi-Objective Genetic Algorithms

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Table 1: Characteristics of DTBA Made of 6 SP (-C1, C2, C2, C1); RF voltage=2.2 MV, h=935

Parameter	DTBA
Circumference [m]	561.0
C1, C2 [m]	24.125, 22.625
ID_A, B, C [m]	2.606, 3.180, 3.732
ν_x, ν_y	57.20, 20.30
Natural ξ_x, ξ_y	-73.05, -105.72
ϵ_x $[pm]$	131.24
α_c $[10^{-4}]$	0.99
U_0 [MeV]	0.36
b_l $[mm]$	1.71

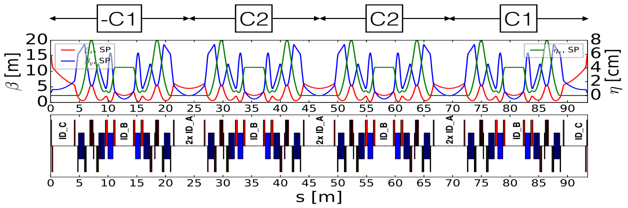

Figure 3: A DTBA SP: -C1, C2, C2, C1.

(MOGA) [8], aiming to increase the DA and Touschek lifetime of the DTBA lattice.

Linear Optics Optimisations

A very useful technique inherited from the ESRF experience is the identification of specific optics knobs, listed in Table 2, that influence a well defined quantity of interest for the linear optics optimisations. As an example, Figure 4 (top and middle) demonstrates how β_x at the ID affects the emittance, DA and Touschek lifetime (for the purposes of this example the β_x scan was performed on a ring made of 24 C2, while keeping all other knobs of Table 2 constant). For a complete optimisation, the parameters of Table 2 have been varied simultaneously using MOGA, by altering all the available quadrupole components, including the quadrupole-field of DQ. During this process the tune of the cell was kept constant and the chromaticity was set to (2, 2). Figure 4 (bottom) shows the optimisation improved the Touschek lifetime by a factor of 2. Note that this improvement is achieved by optimising only the linear optics. Setting number 1133, with a lifetime of 2.35 h, was chosen to continue the optimisation introducing sextupoles and octupoles (at this stage a slightly stronger preference was given to the lifetime optimisation since the DA is expected to be further improved with the inclusion of the injection cell later on; see section "Injection Cell").

Tune-scans with respect to the DA, Touschek lifetime and emittance were performed considering errors and correction for several error seeds. However, as an optimal point has not yet been indicated, larger scans with higher resolution over several tune units will be tackled in the future.

Table 2: Optics Tuning Knobs Inherited from the HMBA Lattice

Parameter	Location	Influence
α_y	SF	V detuning with V amplitude
$K4$	OF	H detuning with H amplitude
ψ_y	SF-SF	Crossed detuning
β_x	ID	ϵ_x
β_y	SF	ϵ_x and nat. ξ

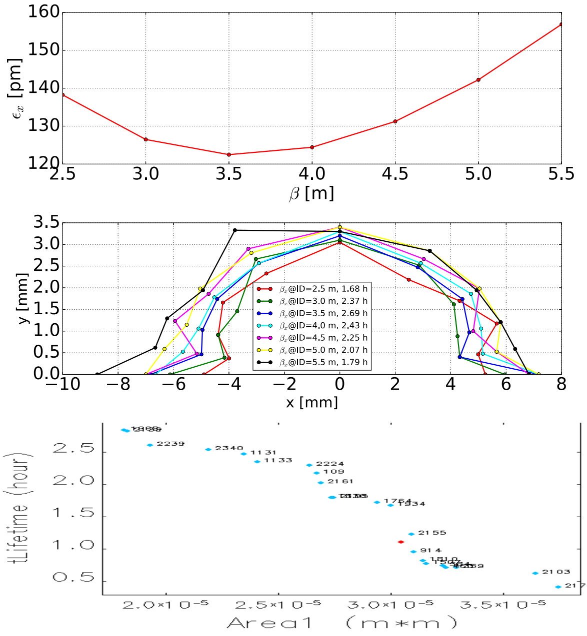

Figure 4: Effect of β_x on ϵ_x (top) and on DA and Touschek lifetime (middle). Bottom: Linear optics optimisation using MOGA. Red dot: initial point, blue: Pareto front of best found solutions to date.

DTBA Non-linear Optimisations

After an improved DA and Touschek lifetime were found with the linear optics optimisation, a non-linear optics optimisation was performed using MOGA. For this part of the optimisation the sextupoles of the SP were divided in 6 families: SD1, SF1, SD2 in C2, and SD3, SF2 and SD4 in C1; C1 and C2 have an octupole family each. The chromaticity was matched to (2, 2) using SD1 and SF1 and the DA area and Touschek lifetime were optimised using SD3, SD4, OF1 and OF2. The results of the Pareto front are shown in Figure 5; the lifetime has increased from τ = 2.36 h to 2.81 h.

ERRORS AND CORRECTION

Random alignment and roll errors of 100 µm and 200 µrad respectively were set on all magnets apart from DQ, QF6 and QF8, where half of these values were set. Orbit, optics and

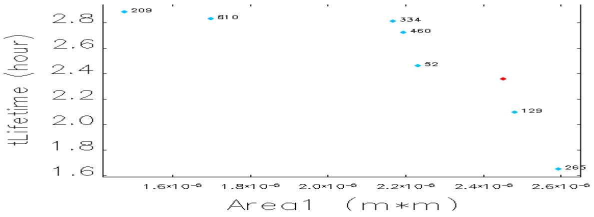

Figure 5: Non-linear optics optimisation of the DTBA lattice using MOGA. Red dot: initial point, blue: Pareto front of best found solutions to date.

coupling were corrected following [9] and the DA (computed at the ID_A centre) and lifetimes were estimated for 10 seeds of errors. The resulting DA computed at the ID_A centre and lifetime, averaged over 10 seeds, reduced from −6.2 mm and τ = 1.6 h, when no errors were present, to −3.6 ± 0.1 mm and τ = 0.4 ± 0.1 h, i.e. the DA with errors is 60% of the DA with no errors. Figure 6 shows the effect that the errors and the RF cavity have on the DA.

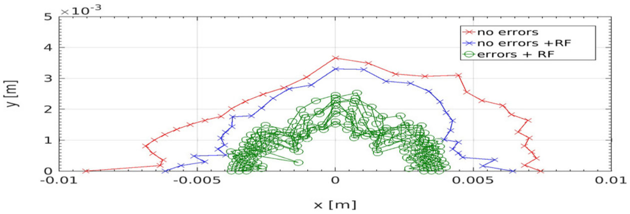

Figure 6: DA. Red: no errors and no RF cavity, blue: no errors, with RF cavity, green: with errors and RF cavity.

INJECTION CELL

Following the design of the ESRF injection cell, the DTBA injection cell was created by splitting the last longitudinal-gradient dipole in two. The location of the last quadrupole can be adjusted to obtain the required β_x at the end of the drift while keeping the phase-advance of the cell constant.

DA and MA Including Injection Cell

Three injection cells were designed with different β_x at the injection straight: β_x = 20 m, β_x = 30 m and β_x = 45 m. Figure 7 (top) shows the DA of each scenario, calculated at the centre of ID_A (continuous line) or at the injection cell (dashed line). The DA of a DTBA ring, calculated at the centre of ID_A, without including the injection cell, is shown in cyan. The continuous lines are very close to the cyan line, which means the DA with no errors is not negatively affected when including the injection cell. From the dashed lines it can be seen that the injection cell with β_x = 45 m results in the best DA.

The negative effect the injection cell has on the Momentum Aperture (MA) can be seen in Figure 7 (middle), where the MA for a DTBA ring with (continuous line) and without (dashed line) the injection cell are compared for the three β_x cases. Since the lattice with β_x = 20 m (red line) results in the best MA, and has an acceptable DA with no errors, this case is chosen to be optimised using MOGA following the same procedure described in the "Lattice Optimisations" section. The Pareto front to date of the linear optics optimisation is presented in Figure 7 (bottom). It is clear that the Touschek lifetime has been greatly impacted by the presence of the injection cell. Note that one quadrupole of the injection cell has a gradient of 90 T/m and will be tuned in future versions; all other gradients are below 70 T/m. Additional studies to improve the DTBA ring including the injection cell, such as non-linear optics optimisation, are already underway.

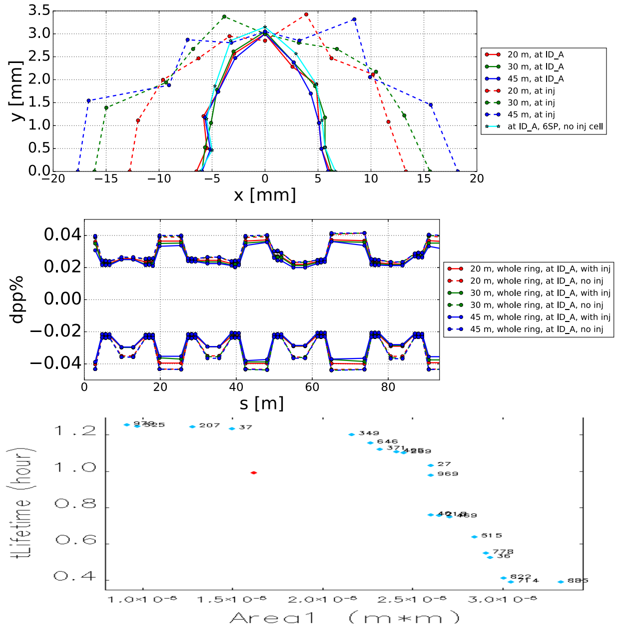

Figure 7: Top: DA without errors calculated at the centre of ID_A (cont. line) or at the centre of the injection cell (dashed line); all lines apart from the cyan one are for a DTBA ring including the injection cell. Middle: MA without errors for a DTBA ring with (cont. line) and without the injection cell (dashed line). Bottom: Linear optics optimisation without errors, including the injection cell, using MOGA. Red dot: initial point, blue: Pareto front of best found solutions to date.

CONCLUSIONS

The Double Triple Bend Achromat (DTBA) lattice is designed for a 3 GeV Light Source. Combining the best characteristics of the HMBA lattice developed at ESRF, and of the DDBA lattice developed at Diamond, the DTBA lattice has 48 straight sections and achieves a ϵ_x=131 pm with ~ 6 mm DA at ID_A. Analysis in the presence of errors and RF cavity shows the DA is 60% of the DA when no errors are present. The DA, with no errors, at the centre of the injection section is as large as ~ 17 mm and the lifetime is ~ 1.2 h; the estimated DA in the presence of errors is ~ 10 mm. Future work will focus on further optimisations including the injection cell.

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