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Alekou, Androula (DLS, JAI and Oxford University, UK) *et al*

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STUDY OF A DOUBLE TRIPLE BEND ACHROMAT (DTBA) LATTICE FOR A 3 GeV LIGHT SOURCE

A. Alekou*, R. Bartolini, DLS, JAI and University of Oxford, UK,
N. Carmignani, S. M. Liuzzo, P. Raimondi, ESRF, France, T. Pulampong, R. P. Walker, DLS, UK

Abstract

Starting from the concepts of the Hybrid Multi Bend Achromat (HMBA) lattice developed at ESRF and of the Double-Double Bend Achromat (DDBA) lattice developed at Diamond, we present a new cell that includes all the advantages of the two designs. The resulting Double Triple Bend Achromat (DTBA) cell allows for a natural horizontal emittance of less than 100 pm with a large dynamic aperture and lifetime. It includes two straight sections, for insertion devices, five and three meters long. The lattice is consistent with the engineering design developed for the ESRF-EBS lattice and the layout and user requirements of Diamond. The characteristics of the cell are presented together with the results of the optimisation process.

INTRODUCTION

The design and optimisation of a Double Triple Bend Achromat (DTBA) cell for a next generation 3 GeV synchrotron light source is presented. The design of DTBA, which comes from a modification of the ESRF HMBA 6 GeV cell [1] used for the future ESRF upgrade, is inspired by the DDBA lattice studied as an upgrade of the Diamond Light Source [2, 3]. Taking advantage of the lower gradients and fields required for a 3 GeV energy, the magnets are shorter and the central dipole is removed obtaining an additional central straight section of more than 3 m (ID_B, see Fig. 1). The optimisation of the DTBA cell in terms of emittance, Dynamic Aperture (DA) and lifetime is presented, together with possible solutions of fitting this new lattice to the future upgrade of the Diamond Light Source.

DTBA LAYOUT

The DTBA cell optics and magnets layout are displayed in Fig. 1. The DL dipoles have a longitudinal gradient that has been optimised for larger dispersion at the sextupoles and minimal horizontal emittance [4]. The central dipoles (DQ) are combined function magnets that reduce the emittance thanks to the increased horizontal damping partition number (J_x) and allow to enforce a -I transformation between the sextupoles. A family of octupoles is also required for DA reasons.

Cell-length Adaptation

The DTBA cell has been designed starting from the ESRF HMBA cell that has a length of 26.4 m. When deciding the main parameters of the DTBA lattice, the characteristics of the 3 GeV Diamond Light Source Upgrade (Diamond-II) have been taken into account. Diamond-II will consist of 24 cells placed in a circumference of 561.0 m. Therefore, an initial DTBA cell of 23.375 m, named C0, was created by reducing the length of the HMBA dipoles, keeping the drift lengths the same, and by ensuring the quadrupole gradients do not exceed the given limit of 70 T/m (all quadrupoles have gradients below 40 T/m, apart from the two closest to the centre (QF6 and QF8, see Fig. 1) that have gradients of just below 70 T/m).

The Diamond lattice has a 6-fold symmetry, with a super-period composed as (-C1, C2, C2, C1). The characteristics of various DTBA lattices made of 24 C0, 24 C2 cells and 6 super-periods of C1 and C2 are presented in Table 1. C2 is symmetric and its length is scaled from C0 following the same steps used to create C0 from the HMBA cell (described above); C1 is asymmetric and is obtained from C2 by adding

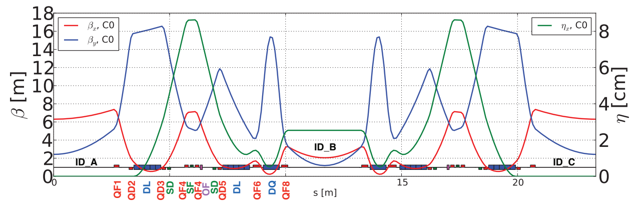

Figure 1: C0 twiss and layout; red: quadrupoles, blue: dipoles, green: sextupoles, magenta: octupoles

Table 1: Characteristics of DTBA Lattices Made of 24 C0, 24 C2 or 6 Super-Periods of (-C1a/b, C2, C2, C1a/b); ID_B and ID_C are the middle and end straight sections respectively; RF voltage=2.2 MV, h=935.

	C0	C2	C1a	C1b
Circ. [m]	561.0	543.0	561.0	561.0
Cell [m]	23.375	22.625	24.125	24.125
ID_B [m]	3.18	3.18	3.18	3.18
ID_C [m]	2.606	2.606	3.821	3.788
ν_x	57.20	57.20	57.39	57.37
ν_y	20.30	20.30	20.30	20.30
Nat. ξ_x	-78.8	-81.0	-81.1	-84.5
Nat. ξ_y	-105.5	-114.2	-114.6	-127.4
ϵ_x [pm]	99.9	111.4	114.0	113.5
α_c [10^{-4}]	1.13	1.02	1.02	0.87
U_0 [MeV]	0.38	0.49	0.48	0.49
b_l [mm]	2.08	2.19	2.10	1.95

* androula.alekou@physics.ox.ac.uk

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

1.5 m to the last drift. The matching solutions for C2, which is used as the basic cell for the following lattice optimisations, are described below.

DTBA CELL OPTIMISATIONS

Aiming to increase the DA and Touschek lifetime of C2, linear and non-linear optics optimisations were performed using Elegant [5] and Accelerator Toolbox (AT) [6].

Linear Optics and Tune-scan Optimisation

Following the experience of ESRF, each of the optics knobs listed in Table 2 has an impact mainly on a given quantity of interest for the optimisations. Therefore, for the linear part of the optimisation, the parameters of Table 2 have been varied one at a time by altering the available quadrupole components, including the quadrupole-field of DQ. An example of the optimisation process for different values of α_y is presented in Fig. 2 (top). Figure 2 (bottom) shows the improvement in DA and lifetime before and after the linear optics optimisation. The negative side of DA, which is of interest for injection efficiency, is increased by about 1 mm; however the lifetime decreased from 3.19 h to 1.80 h (zero current bunch length). The lifetime calculations were performed using a current of 300 mA, 900 bunches, and 10% coupling.

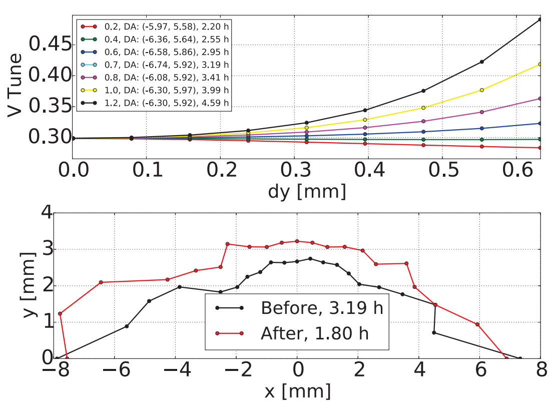

Figure 2: Top: C2 linear optics optimisation example: vertical detuning with vertical amplitude, DA and lifetime, for α_y varying from 0.2 to 1.2 (initial $\alpha_y = 0.7$, cyan line). Bottom: DA and lifetime comparison of C2, before and after optimisation (black and red lines respectively).

A tune-scan over several tune units was also performed with respect to DA and Touschek lifetime. Note that although no errors were applied up to now, for the purpose of this scan small alignment errors (0.1 μm) where applied on all magnets of the used lattice, and no correction was performed in order for the resonances to be highlighted. As can be seen in Fig. 3, there are several visible regions with lifetime of about 3 h and a large zone that is forbidden due to systematic resonances; however, only the region at integer horizontal tune 56 results in DA<−8 mm.

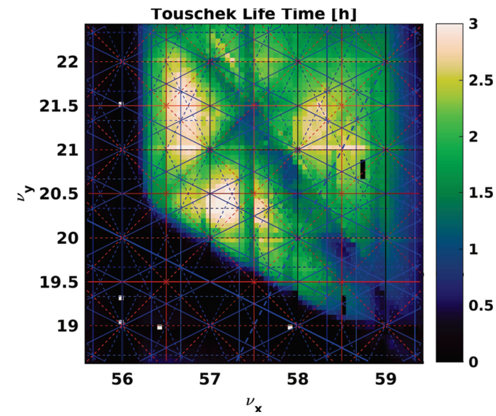

Figure 3: C2 tune-scan with respect to lifetime; $\epsilon_y = 5$ pm, i.e. coupling=4%.

Non-linear Optics Optimisation

For the non-linear optics optimisation of DA and lifetime, the sextupoles of C2 were divided in 3 families [8]. While scanning the K2 and K3 values of SD2 and octupoles respectively, sextupoles SD1 and SF have been used to correct the chromaticity to (2, 2). As can be seen in Fig. 4, the best negative DA value is found at K2=−425 1/m^3 and K3=−48 000 1/m^4.

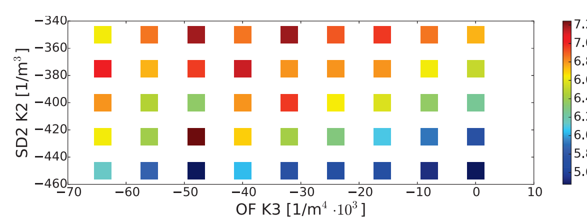

Figure 4: C2 non-linear optimisation using SD2 and OF.

C1 OPTIONS

C1 is asymmetric, with the last straight section longer by 1.5 m compared to C2. An end-drift of 4.15 m is aimed, to host the same equipment that is currently installed in these sections. To keep the lattice symmetry, 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 various options that were considered for the C1 design are described below and their layouts are presented in Fig. 5. The last five quadrupoles have been used for the matching of the following twiss parameters: $\alpha_x = 0$, $\alpha_y = 0$, $\eta'_x = 0$, ν_x and ν_y. Although, ideally, only the quadrupoles after the last sextupole should be used, in order to keep the sextupole compensation scheme untouched, small optics

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changes at the last sextupole can be recovered by adjusting the sextupole strengths.

The characteristics of a DTBA lattice with 6 super-periods, for each C1 option, are given in Table 1. It should be noted that although the tunes of both C1 versions are close to those of C2, alternative solutions will be investigated such that the tune-matching will be exact. Future work will also aim to further increase the end-drift (ID_C) length.

C1a Solution

Following the design of the ESRF injection cell, C1 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. This is one of the positive characteristics of this design, the fact that the same cell can be used as an injection cell simply by moving the last quadrupole further out, increasing in this way β_x. However, as can be noted in Fig. 5 (top), at the end of the cell η_x=5.5 mm instead of zero, and the tune values are close but not identical to those of C2.

C1b Solution

This C1 version is created solely by adding 1.5 m at the end of C2, and an additional quadrupole to aid with the constraints' matching. In this version at the end of the cell $\eta_x = 0$; however, the tune is not matched to the exact values of C2.

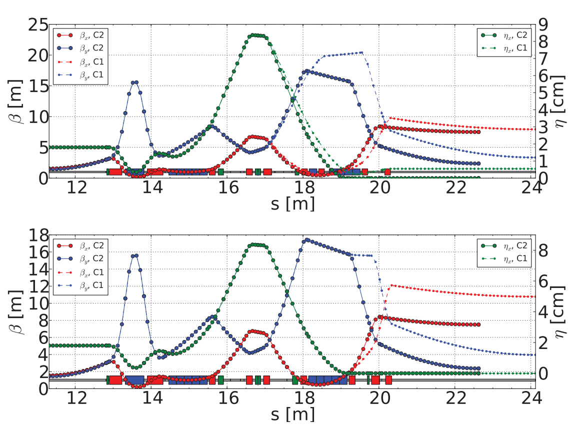

Figure 5: C1 options; top: C1a, bottom: C1b (twiss shown from the middle until the end of the cells).

DTBA NON-LINEAR OPTIMISATION

A lattice consisting of 6 super-periods including the above C2 optimisation results and the C1b solution for C1 is being optimised using MOGA (Multi-Objective Genetic Algorithms) [7]. The sextupoles of the super-period are divided in 6 families: SD1, SF1, SD2 in CELL2, and SD3, SF2 and SD4 in C1. C1 and C2 have an octupole family each. SD1 and SF1 are used to match chromaticity to (2, 2), and the remaining SD3, SD4, OF1 and OF2 are used for the optimisation of the DA area and Touschek lifetime [8]. Figure 6 presents the initial point (red), that has less than 1.2 h lifetime, and the Pareto front of the best found solutions to date (blue).

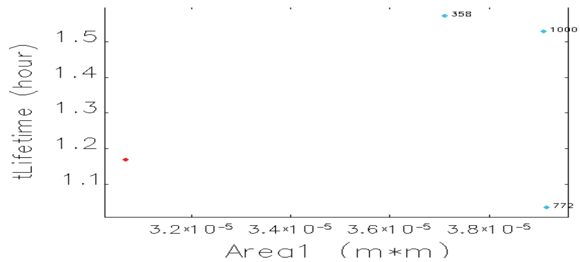

Figure 6: Non-linear optimisation of DTBA lattice using MOGA. Red dot: initial point, blue: Pareto front of best found solutions to date.

CONCLUSIONS

A Double Triple Bend Achromat (DTBA) lattice has been designed for a 3 GeV Light Source by combining the characteristics of the Hybrid Multi Bend Achromat (HMBA) lattice developed at ESRF and of the Double-Double Bend Achromat (DDBA) lattice developed at Diamond. Two different cells have been designed, C1 and C2, to reproduce the specific lattice periodicity of Diamond-II. The DTBA C2 cell can achieve ϵ_x=111.4 pm with 8 mm DA at injection at the central straight section and almost 2 h lifetime. Using MOGA for the optimisation of the super-period made of C1 and C2, more than 7 mm DA at injection and 1.5 h lifetime have been achieved to date. More optimisations are in progress and alternative C1 solutions are being investigated. Finally, a lattice with applied errors and corrections will be studied.

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