ENGINEERING INTEGRATION CONSTRAINS ON THE BEAM PHYSICS OPTIMISATION OF THE DDBA LATTICE FOR DIAMOND

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Abstract

The design and optimisation of the new DDBA lattice for Diamond has been performed taking fully into account, from the early stages, the geometry and the engineering integration constraints. In this paper we review the evolution of the DDBA cell, the rationale for its modification and the optimisation strategy used.

INTRODUCTION

Underpinned by previous lattice upgrade studies [1-2-3] the Diamond Light Source has started project [4] for the installation of a Double Double Bend Achromat in cell two of the existing lattice, to serve the VMX beamline with a narrow gap ID rather than a short canted out-of-vacuum ID as originally planned [5]. Magnet design [6], engineering integration [7], vacuum and diagnostics design is well on the way with the aim of commissioning with beam by the end of 2016. At present a second DDBA cell upgrade is awaiting funding, and the use of a third DDBA cell to generate space for a third harmonic cavity is under investigation.

While the original Accelerator Physics lattice design had only rather general constraints, forcing any lattice modification in the existing tunnel and maintaining the beamline layout, the actual project phase has required a detailed engineering integration with all the technical subsystems and a conspicuous number of requirements had to be properly integrated in the lattice design.

In this paper we review the most recent Accelerator Physics studies on DDBA with emphasis on those driven by the interaction with other technical subsystems and with the engineering integration of the lattice.

THE DOUBLE-DBA CELL LAYOUT

The DDBA cell is a modified 4BA cell providing a new mid-straight section for additional insertion device. The comparison between Diamond DBA and new DDBA cell is shown in Figure 1. The main parameters of Diamond and modified ring with one DDBA cell are reported in Table 1.

To fit the new DDBA cell into the machine and keep beamline position, the total circumference of the ring is shorter by 29 mm. This circumference length was shown to be compatible with the changes in the RF frequency of the Diamond accelerators chain [8].

The optics of the cell was carefully tailored to allow the installation of a narrow gap ID in the mid straight section. To this aim we had to opt for a very compact magnet arrangement with no vertical focussing quadrupoles in the cell, deferring the vertical focussing to the introduction of gradients in the dipoles.

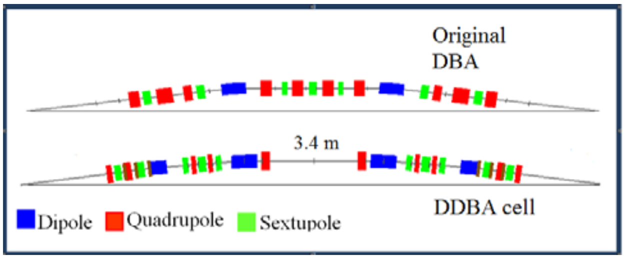

Figure 1: Schematic layout of DDBA cell with respect to the existing Diamond DBA.

Table 1: Main parameters of Diamond lattice and modified lattice with a DDBA cell.

Parameters	DLS	DDBA
Energy [GeV]	3.0	3.0
Circumference [m]	561.6	561.571
Emittance [nm.rad]	2.75	2.69
Tune Point [Q_x / Q_y]	27.20/ 13.37	29.18/13.28
Chromaticity(ξ_x / ξ_y)	-80.4 / -35.6	-78.4/ -41.3
Mom. compaction	1.6e-04	1.5e-04

One of the most difficult optimisation parameter was the length of the mid cell straight section. A longer length poses stronger requirement on the vertical focusing in the dipoles. The initial 3 m straight section was further lengthened to 3.4m to fit one of the standard ID vessel currently used in the rest of the ring. The optics was eventually matched after extensive MOGA runs on the magnet length, positions and requiring 14 T/m on quadrupole component of the dipole. This gradient is achieved with a complex design of the dipole pole profile [6]. The lack of space in the mid-straight section pushed toward a design without sextupoles between the central dipoles. This solution was eased by the use of a dispersion bump after dipole 1 and before dipole 3. In turn this required the introduction of strong quadrupoles at the cell ends with a gradient reaching 65 T/m. The small bore required to achieve such gradients was the main driver for a reduction of the vacuum pipe to a 29x20mm^2 elliptical shape through most of the DDBA cell. Again the lack of space was the driver for combining dipole correctors and skew quadrupoles in the sextupoles. This concept is a copy of the one already existing in the main Diamond sextupoles. Octupole magnets did not provide significant benefits to the beam dynamics and were not included in the lattice.

The integration of correctors in the sextupoles and the elimination of sextupole from the mid-straight section had a detrimental impact on the performance of the orbit correction system. For this reason a pair of additional dedicated correctors had to be included between the dipole and the quadruples at the ends of the mid-straight section. In order to keep the quad-to-quad distance to 3.4 m the length of these correctors was reduced to 102 mm including coils overhang in a combined H to V design.

Finally, while the length of the quadrupoles was originally left as an optimisation parameter, the request of standardising the quadrupole design to have one single type (0.25m) throughout the cell, was proven to be workable. A similar request to standardise the sextupoles in the DDBA cell to 0.175m length and the quadrupole gradient in the combined function dipole was also accommodated. The details of the magnets design can be found in a companion paper [6].

LATTICE OPTIMIZATON

The beam dynamics in the single DDBA cell lattice were optimised using Multi-Objective Genetic Algorithm (MOGA) in elegant [9], using the quadrupole strengths, sextupoles strength and positions as fit parameters, within the constraints listed in the previous paragraph.

The main optics constraint was to ensure a small β_y (< 2m) at the middle of the mid-straight section, to allow the operation of a small gap ID. The optimisation of the quadrupoles and linear optics was then followed by the optimisation of the sextupoles to achieve good dynamic aperture (DA) and Touschek lifetime, in separate MOGA runs. Chromaticity is corrected to be 2 for both horizontal and vertical plane by two families of sextupoles. Six families of existing sextupoles and new sextupoles in DDBA are variables for MOGA optimization. The symmetry of the sextupoles in DDBA are broken giving more variables for the optimization. Engineering physical aperture with full details has been included in the calculations. The quality of the solution was always validated against the dynamic aperture values of the Diamond lattice presently in operation.

The best optics solution provided by MOGA with minimal impact on the DA and Touschek lifetime generated a rather small β_x = 0.4m in the mid-straight section and a shift in the position of the waist in the adjacent straight section. Consultation with the beamlines scientists showed that the large horizontal divergence of the photon beam produces an unacceptable photon flux loss at the first mirror and an additional constraint β_x > 1.5 m was included in the optimisation. At the same time the position of the waist in the adjacent straight sections was moved back with very modest increase in the vertical β_y.

Due to smaller bore radius of the magnets in DDBA cell, the maximum beta functions are carefully controlled with stronger constraints than the existing DBA cell. Only 20 m for vertical beta function and less than 15 m for horizontal beta function are fixed in DDBA. The linear optic optimisation for Diamond was further complicated by the existence of customised straight sections that further reduce the overall symmetry. Double-mini beta in I09 and I13 [10] and planed small beta functions in long straight section in I21 have to be preserved as the new DDBA section will be installed. The natural emittance is constrained not to exceed the existing 2.75 nm-rad. The fractional tunes are matched below the half integer to avoid resistive wall instability which has strong influence in machine with narrow gap IDs like Diamond.

The final optics function is shown in Figure 2 with a comparison between the new optic including DDBA cell and the original Diamond optic. As a result the final values obtained for the Touschek lifetime are 21±2 h (average over 5 error seeds) for the existing lattice and 18±1h (over 50 error seeds) for the single cell DDBA lattice. These values refer to the operation with 300 mA, 900 bunches, 0.3 % coupling, 2.6 MV, with engineering apertures, with errors, orbit and tune corrected and constitute an acceptable reduction over the present operation. The Dynamic Aperture is also slightly reduced but still sufficient for good injection (see Figure 4).

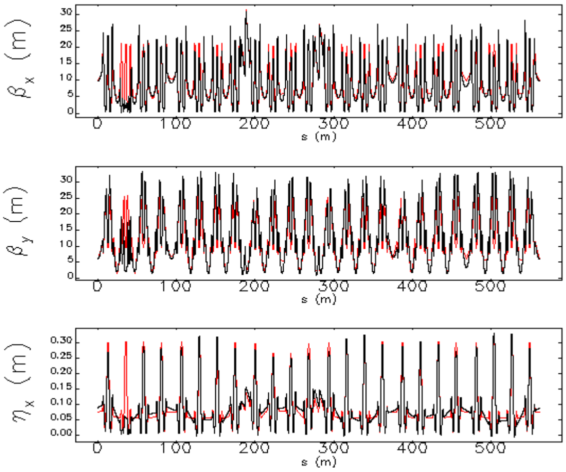

Figure 2: Optic functions including DDBA in cell2 (black) with respect to the original optic (red).

ENGINEERING APERTURES

Realistic physical apertures were created based on engineering design of the vacuum pipe. In the simulations, the elements in the lattice were split to match every step changes in the physical aperture. This has allowed a very accurate analysis the effect of the apertures on the particle losses distribution. The simulations include both horizontal and vertical collimator set at 12 mm and 3.5 mm respectively as in standard operation. In DDBA cell vertical aperture at ID is 2.5mm half gap.

The lack of space for an antechamber and the results of the thermal analysis of the illumination of the vacuum pipe have resulted in the introduction of a number of bumps in the inner horizontal profile of the vacuum pipe

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necessary to cast a shadow to protect uncooled surfaces. These bumps protrude inside the pipe by no more than 3 mm and did not impact significantly the impedance and loss factor of the pipe. However they have been included in the injection and Touschek lifetime simulations to check that they do not capture significant losses. It turns out that the collimators are still very effective in capturing most of injection and Touschek losses in presence of realistic lattice errors.

CLOSED ORBIT CORRECTION

The closed orbit correction scheme was designed to correct the orbit in presence of misalignments in the DDBA cell including transverse and longitudinal random displacement (100 μm), rotation (100 μrad) and magnet strength error. The effect of the new ID in DDBA was models with kickmaps. Despite the 10 independent horizontal and vertical correctors embedded in the sextupole of the DDBA cell, it turned out that the removing the sextupoles from the mid-straight section has created a poor sampling of the phase advance preventing a good orbit correction. For this reason a short dipole corrector had to be reinstalled in the cell, in the mid-straight section. The lack of space forced a very compact design of an integrated horizontal and vertical corrector [4]. The final orbit correction scheme is made therefore of a system of eight correctors and eight BPMs shown in Figure 3. The strength limit on the corrector was set to 0.8 mrad as in the other correctors of the ring. Sub-micron orbit control at the ID is proved to be feasible.

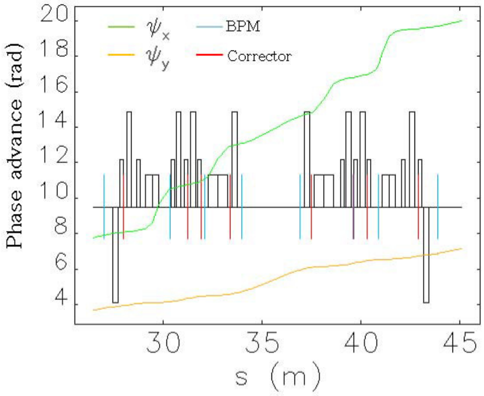

Figure 3: BPMs and correctors in DDBA cell.

In order to ease cooling of the portion of the vacuum chamber irradiated by synchrotron radiation, a copper chamber was used in the DDBA as much as possible in place of stainless steel that is used elsewhere in the ring. Ray tracing showed that the locations after the dipoles require a cooled copper pipe as otherwise the heating and mechanical stress become excessive [7]. The presence of cooper vacuum tubes has posed some problems to the operation of the fast orbit feedback (FOFB), since the orbit correctors that are placed over a copper vessel have their high frequency response distorted by the eddy current flowing in the pipe. For these reasons we considered splitting the orbit correction task in a static orbit correction system operating with the aforementioned eight correctors and eight BPMS, and the FOFB which operates without the correctors located on the copper vessels and is therefore based on a system of six correctors located on stainless steel vessels and six BPMs.

This scheme was proven to be effective in correcting large static (or slow) orbit excursion and the much reduced orbit distortion (up to ±50 μm peak-to-peak) that could be generated at high frequency components in the existing ring. Small, fast orbit bumps to control the position and angle of the source point at the ID can also be accommodated.

MACHINE IMPERFECTIONS

Misalignments and multipole errors in magnets were extensively studied. Both systematic multipole from design and random multipole error scaled from the existing machine are included. Systematic multipole errors are taken from the magnet at maximum strength. Using 50 seeds and correcting orbit, tunes and chromaticity we obtained the dynamic aperture shown in Figure 4. The dynamic aperture of -10 mm, it is considered to be a safe margin for off-axis injection at Diamond.

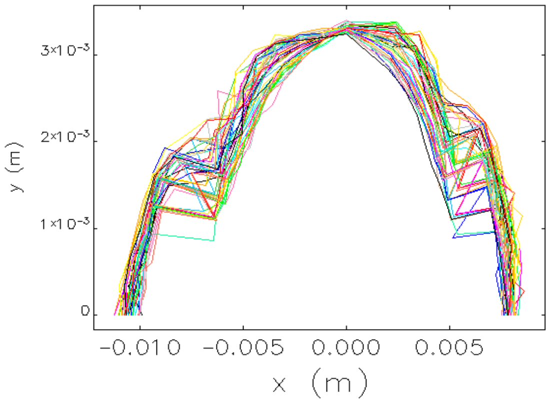

Figure 4: Dynamic aperture of 50 random machines.

CONCLUSION

The design of the DDBA cell in its final stage and it has already undergone a full engineering integration with other technical subsystems. Purchasing of equipment has started in view of operating the new ring by the end of 2016.

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