STATUS OF HIGH BRIGHTNESS OPTICS FOR THE DIAMOND-II STORAGE RING UPGRADE

B. Singh, N. Blaskovic Kraljevic, H. Ghasem, I. Martin, Diamond Light Source, Oxfordshire, UK

Abstract

We report the status of the high-brightness, low-beta optics for the Diamond-II storage ring upgrade. Investigations of lifetime and injection efficiency will be presented. MOGA optimisation studies have been conducted to improve the nonlinear performance, including by increasing the number of sextupole families and varying the octupoles strengths. We present complementary methods to improve the nonlinear dynamics by optimizing sextupoles, octupoles strengths and linear tunes. Finally, we report the impact of insertion devices on lifetime and dynamic aperture and so on injection efficiency.

INTRODUCTION

To further increase the brightness of the Diamond-II storage ring, separate investigations into reducing either the emittance or the beta-functions at the IDs have been carried out for the Diamond-II TDR lattice [1-3]. Latest results for the lattice solution with low beta functions in the insertion straights will be presented in this paper.

The initial tuning of the low beta lattice suffered from low lifetime and small dynamic aperture (DA) leading to poor injection efficiency (IE) at -3 mm offset. Further studies outlined in this paper were successful at improving the Touschek lifetime (TL) to ~1.4h and the dynamic aperture to around 4 mm. This would allow beam to be injected at -3 mm using either the standard 4 kicker bump injection scheme or the transparent kick and cancel injection scheme planned for top-up operation [4].

The linear and nonlinear optimization was initially carried out using OPA. This was sufficient to develop a solid baseline solution. Following this, a Multi-Objective Genetic Algorithm MOGA [5] was used for optimization of the TL and IE and good progress was made. This MOGA optimized optics will be presented in this paper. One important change for the MOGA-optimised optics was to split the six families of sextupoles into ten families according to the local beta functions. These MOGA optimized sextupole families were obtained first for the nominal optics and resulted in significant improvement in TL [5]. The same method has been applied for the low beta optics optimization, resulting in significantly higher TL, IE and DA (both on and off momentum).

LOW BETA OPTICS

The optical functions and main parameters of the low-beta lattice are presented in Fig. 1 and compared to the nominal lattice in Table 1. The strengths of the sextupoles and octupoles obtained from the OPA optimisation were used as the starting point for these studies.

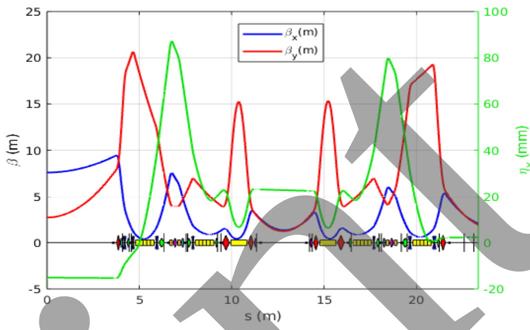

Figure 1: Optical functions in cell 1 for the low-beta optics.

Table 1: Parameters for Nominal and Low Beta Optics

Parameter		**Nominal**	**Low Beta**
Q_x		54.14	58.12
Q_y		20.24	21.28
$[\xi_{x0}, \xi_{y0}]$		[-68, -89]	[-72, -101]
ε_x (no IDs) (pm)		162	139
ε_x (all IDs) (pm)		121	127
σ_E (no IDs) (%)		0.094	0.096
σ_E (all IDs) (%)		0.110	0.110
α_C (10^{-4})		1.03	1.10
$\beta_{x/y}$ (m)	Long	8.4/3.4	7.6/2.7
	Standard	5.7/2.3	1.8/1.6
	Mid	2.3/1.7	1.4/1.2
η_x (mm)	Long	5.6	-15.2
	Standard	0.6	2.5
	Mid	22.1	22.0

MOGA OPTIMIZATION

MOGA was used to improve the beam lifetime (TL) and injection efficiency (IE). The variables being adjusted were the horizontal and vertical tunes, the strengths of the ten families of sextupoles and both families of octupoles. Five machine error seeds were used for each possible lattice solution, and the mean TL and IE were used as inputs to the optimiser, to find a solution robust against any specific set of machine errors. Further details of the optimisation method and parameters are given in [5].

A series of three successive optimisation runs were performed, taking the optimum from one run as the input to the following one. The search space was constrained with the horizontal tune between 58.10 and 58.25, the vertical tune between 21.20 and 21.31, the sextupole strengths to within ±100 m^{-3} around the previous run's optimum and the octupole strengths were allowed to take any value within the power supply range. As the sextupole strengths were allowed to vary freely within the established ranges, the chromaticity was then corrected to be in the range of 2 to 3 for each candidate solution before evaluating the lifetime and injection efficiency, to ensure that the chromaticity is large enough to mitigate transverse instabilities [6] and that it is small enough for an optimum efficacy of the transverse multi-bunch feedback. The IE was calculated at an injection offset of -3 mm for off-axis injection. Care had to be taken to exclude solutions which returned a high IE when injecting at -3 mm but a much lower IE at smaller injection offsets (Fig. 2a). This was achieved by evaluating the IE at injection offsets of -3 mm, -2.5 mm and -2 mm and selecting the worst of the three as an input to the optimiser. Implementing this change consistently produced solutions with injection efficiency monotonically increasing with injection offsets closer to zero as desired (Fig. 2b).

The results of the three MOGA optimisation runs are shown in Fig. 3, yielding a best lattice solution with a TL of 1.30 h and an IE of 95%, averaged over five machine error seeds.

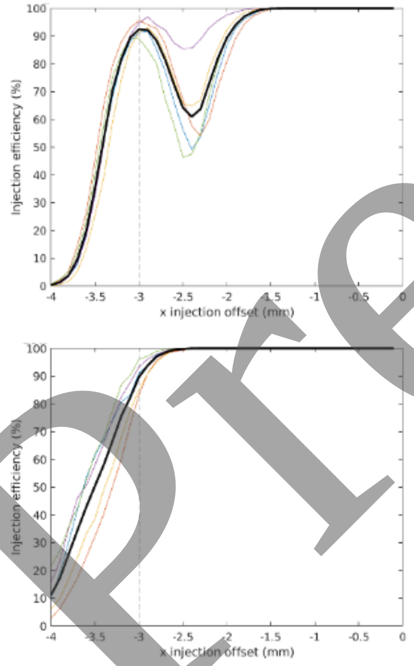

Figure 2: IE as a function of horizontal injection offset, when optimising injection at only -3 mm (top), or at -3 mm, -2.5 mm and -2 mm (bottom). The coloured lines correspond to different machine error seeds; the thick, black line shows their average.

NONLINEAR SIMULATIONS

The best solution after three rounds of MOGA optimisation was used to calculate the TL as well as the on and off-momentum dynamic apertures. Five error seeds were again simulated, and physical apertures were included for both collimators open and closed. Details of the errors used are given in reference [3]. The DAs were calculated using 4096 turns and the TL was calculated using 2500 turns (compared to the 512 turns used in the MOGA optimisation). As a result, the calculated TL dropped from 1.3 h to 1.2 h for V_{RF} = 1.25 MV. The final DAs are shown in Fig. 4.

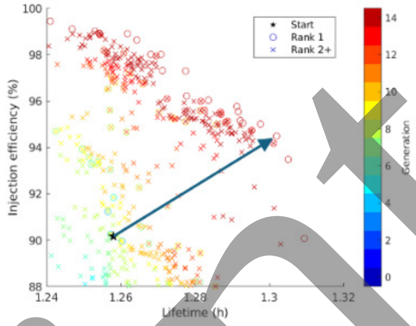

Figure 3: IE and beam TL solutions obtained after MOGA Run 3 using the best solution of Run 2 as a starting point. The solutions are colour-coded according to the MOGA generation number. The initial solution is indicated by a star. Rank-1 solutions (circles) are those that are not dominated by any other solution in that generation.

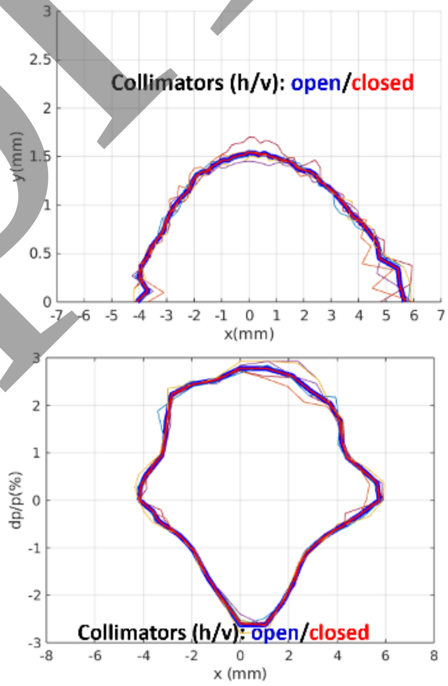

Figure 4: 6D on-momentum (top) and off-momentum x-DA (bottom) for the MOGA optimized solution. Thick lines show the rms values over five error seeds. Aperture limits were included, and the RF voltage was set to 1.25 MV.

IMPACT OF INSERTION DEVICES

The kick-map approach has been used to study the impact of insertion devices (IDs) on the low beta solution. To correct for the linear optics distortions from the 42 IDs planned for Diamond-II, three iterations of LOCO [7] was applied. The residual beta beat is shown Fig. 5. The corrected lattice was used to calculate the on and off-momentum DAs, TL and IE for -3 mm injection offset (1000 turns) for five error seeds. The results are shown in Table 2. The DAs are shown in Fig. 6, and the corresponding momentum aperture with V_{RF} = 1.4 MV used for the TL is shown in Fig. 7.

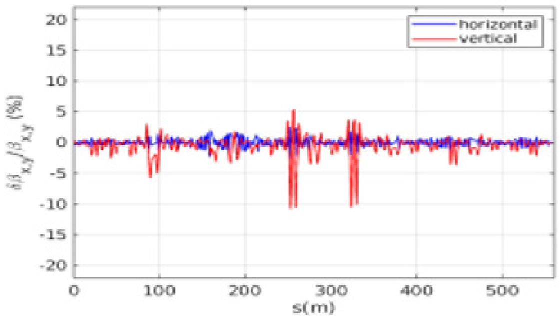

Figure 5: Residual beta beat after 3 iterations of LOCO correction and including 42 ID kick-maps for the MOGA optimized solution.

Table 2: TL and IE with V_{RF} = 1.4 MV

Case	TL (h)	IE (%)
No IDs	1.37±0.06	98.3±0.4
All IDs	1.31±0.06	98.4±0.2

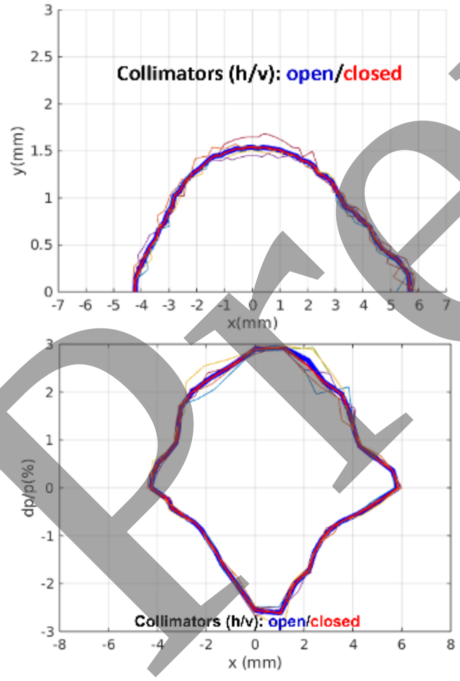

Figure 6: 6D on momentum and off-momentum x-DA(top and bottom) including all IDs after LOCO correction, calculated for 4096 turns. Physical apertures were included for collimators open (blue) and closed (red). The thick lines show the rms values over five error seeds.

EFFECT OF CAVITY VOLTAGE ON TL

Finding the optimal RF voltage for lifetime is a trade-off between increasing the RF bucket height and lengthening the bunch. TL calculations have been carried out as a function of cavity voltage. Results are shown in Fig. 8. The rms TL can be improved to ~1.4 h by increasing the voltage to 1.4 MV for the bare lattice. This drops to 1.3h once the IDs are included and three iterations of LOCO are applied.

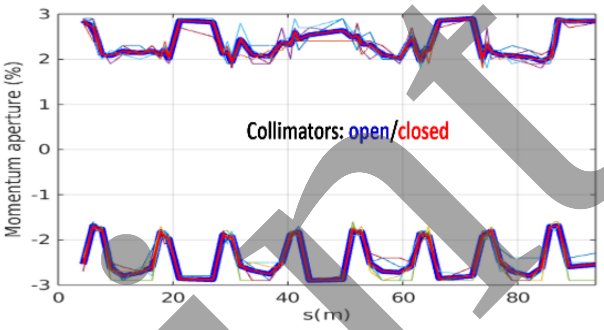

Figure 7: Momentum aperture calculated including the 42 ID kick-maps and physical apertures, with collimators either open (blue) or closed (red) for 2500 turns. Fine lines are for each error seed while thick lines are rms values.

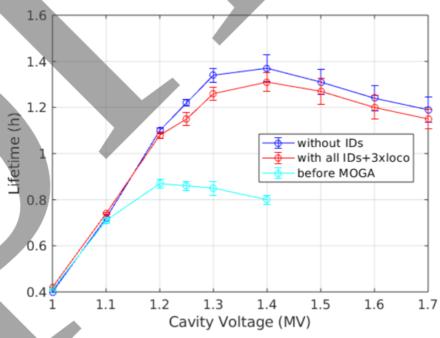

Figure 8: The rms TL as a function of RF voltage for five error seeds. 6D tracking was carried out for 2500 turns and including physical apertures and closed collimators.

CONCLUSION

The lattice tuning option for increasing the photon beam brightness for Diamond-II by lowering the beta functions in the insertion straights has been investigated. The initial low-beta lattice presented in reference [3] was used as a starting point for MOGA optimizations. This led to a new solution at a different tune point and with updated sextupole and octupole settings, for which the TL at V_{RF} = 1.25 MV was increased to 1.2h and an improved on/off momentum DA gave an injection efficiency of over 98% with collimators closed. The TL could be further improved to ~1.4h by increasing the cavity voltage to 1.4MV. When the 42 ID kick-maps were added to the model, the TL was found to reduce to 1.3h even after three iterations of LOCO. Further work is required to understand the reason for this drop and to bring the TL above 1.5 h with IDs closed. However, the optics solution presented in this paper is close to meeting the all the target parameters.

REFERENCES

[1] H. Ghasem, I. P. S. Martin, and B. Singh, “Tunability and Alternative Optics for the Diamond-II Storage Ring”, in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 1495-1497. `doi:10.18429/JACoW-IPAC2022-TUPOMS034`

[2] R.P. Walker, *et al.*, “Diamond-II Technical Design Report”, Aug. 2022.

[3] B. Singh, N. Blaskovic Kraljevic, H. Ghasem, and I. Martin, “Further progress with alternative optics for the Diamond-II storage ring upgrade”, in *Proc. IPAC'25*, Taipei, Taiwan, Jun. 2025, pp. 623-626. `doi:10.18429/JACoW-IPAC2025-MOPS017`

[4] I. Martin *et al.*, “Progress towards kick and cancel injection for Diamond-II”, in *Proc. IPAC'25*, Taipei, Taiwan, Jun. 2025, pp. 1270-1273. `doi:10.18429/JACoW-IPAC2025-TUPM054`

[5] N. Blaskovic Kraljevic, H. Ghasem, I. Martin, and B. Singh, “Linear and Non-Linear Optics Optimisation for the Diamond-II Storage Ring”, presented at the IPAC'26, Deauville, France, May 2026, paper THP2056, this conference.

[6] D. Rabusov, R. Fielder, S. Wang, and I.P.S. Martin, “Single-bunch instabilities and their mitigation in Diamond-II”, in *Proc. IPAC'24*, Nashville, TN, USA, May 2024, pp. 786-789. `doi:10.18429/JACoW-IPAC2024-MOPS33`

[7] J. Safranek, "Experimental determination of storage ring optics using orbit response measurements," *Nucl. Instrum. Methods Phys. Res. A*, vol. 388, Issues 1-2, pp. 27-36, 1997. `doi: 10.1016/S0168-9002(97)00309-4`