ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA159

ALTERNATIVE DIAMOND-II STORAGE RING OPTICS WITH HIGH-BETA SECTION FOR IMPROVED INJECTION

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Abstract

The nominal Diamond-II storage ring optics have been designed to produce a pseudo twenty-four-fold symmetry by maintaining equal phase advance across the long and standard straights. In this paper, the impact of introducing a high beta section in the injection straight and reducing the ring symmetry to one have been extensively investigated. This solution does not require any additional hardware and so can be switched on or off as required. In this paper we present the optics solution and study the expected performance.

INTRODUCTION

In order to improve the dynamic aperture (DA) at the injection point and to increase the safety margin for off-axis injection, an investigation has been conducted to understand the impact of increasing the beta functions in the injection straight of the Diamond-II storage ring. Although increasing the beta functions helps to enlarge the DA, one side effect is that the ring symmetry is reduced from six to one. This can be potentially harmful to the nonlinear beam dynamics, impacting the lifetime.

In this paper we present studies of an injection cell with high beta functions for the Modified Hybrid Six Bend Achromat (MH6BA) Diamond-II storage ring (SR). This solution does not require any additional hardware to be installed, and the required magnet strengths are within the existing tuning ranges [1].

LINEAR BEAM DYNAMICS

To assist in the linear and nonlinear lattice optimisations, the quadrupoles, sextupoles and octupoles either side of the injection straight have been re-defined as new families of magnets. These quadrupoles have been adjusted to provide high beta functions at the injection point, with all other cells remaining unchanged. The optimisation was conducted aiming to maintain the original '-I' phase constraint between the strong focusing sextupoles in the dispersion bumps and from one cell to the next (see Fig. 1, ϕ_I, ϕ_S) [1]. This was only partially achieved, limited by the inverse relationship between phase advance and beta functions in the straight. Final values are given in Table 1.

The optical functions for one cell are shown in Fig. 2 and the main parameters of the ring with and without the high beta injection cell are given in Table 2. As can be seen, the horizontal and vertical beta functions have been approximately doubled and the dispersion leakage of 5.6 mm in the long straight section has been removed.

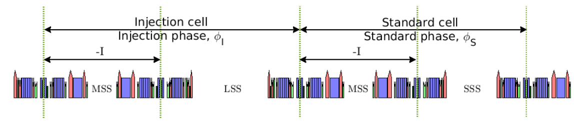

Figure 1: Phase advance conditions. LSS/MSS/SSS stands for Long/Mid/Standard straight section respectively.

Table 1: Phase Advance Conditions from Fig. 1

Phase (rad)	Baseline	High beta
-I	[2.89*π,0.960*π]	[2.73*π,1.08*π]
ϕ_I [x,y]	[4.518*π,1.664*π]	[4.44*π,1.608*π]
ϕ_S [x,y]	[4.512*π,1.698*π]	[4.34*π,1.816*π]

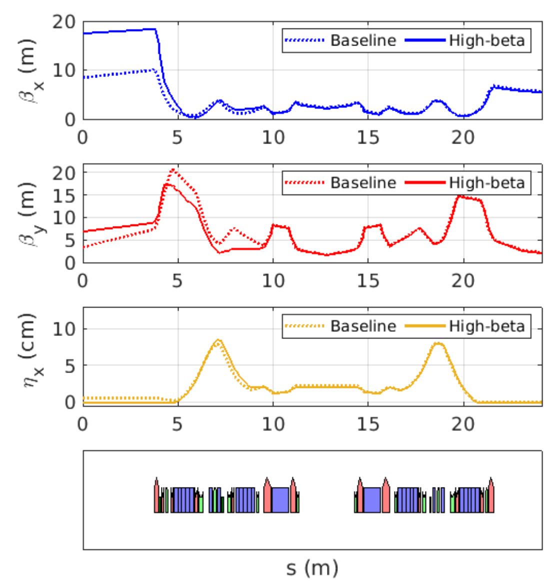

Figure 2: Optical functions for one cell of the ring.

NONLINEAR BEAM DYNAMICS

Due to the larger beta functions in the injection cell, the natural chromaticity changes and needs to be re-corrected using the standard chromatic sextupole families. The remaining sextupole families and all octupole families in the injection cell, long straights and in the arcs were then adjusted to control the tune shifts with energy and amplitude. The final tune shifts with amplitude for the standard and high-beta optics are shown in Fig. 3 and tune shifts with energy out to ±3% energy deviation are shown in Fig. 4. The 4D on/off energy dynamic apertures and corresponding frequency maps are shown in Fig. 5.

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Table 2: Main Parameters of the Diamond-II SR With and Without Injection Cell

Parameters	**Baseline**	**High-beta**
Energy (GeV)	3.5	3.5
Tune [x,y]	[54.14, 20.24]	[54.14, 20.21]
Emittance (pm)	161.5	164.7
En. spread ($\times 10^{-4}$)	9.38	9.37
Mom. com. ($\times 10^{-4}$)	1.03	1.03
β_x (m)@LSS	8.44	17.62
β_y (m)@LSS	3.41	7.01
η_x (mm)@LSS	5.58	−0.07

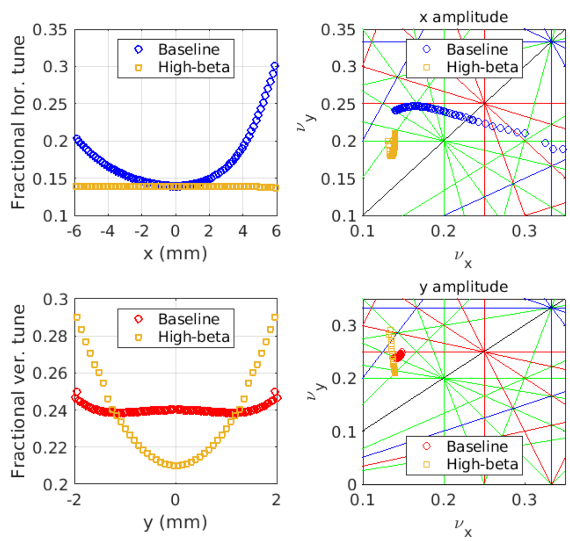

Figure 3: Tune shift with horizontal (x) and vertical (y) amplitudes and corresponding tune diagrams.

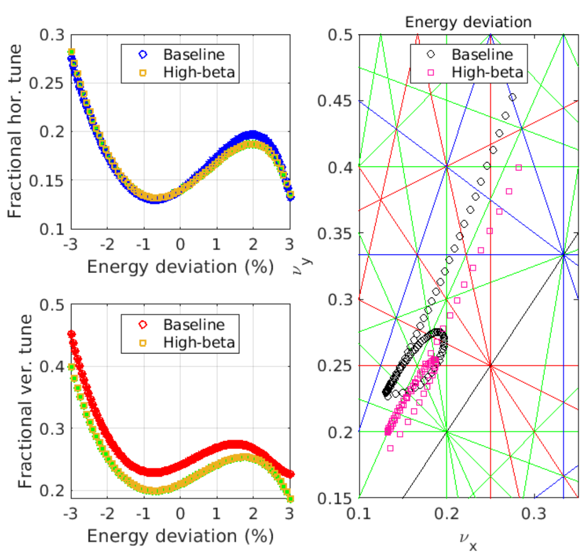

Figure 4: Tune shift with ±3% energy deviation and corresponding tune diagram.

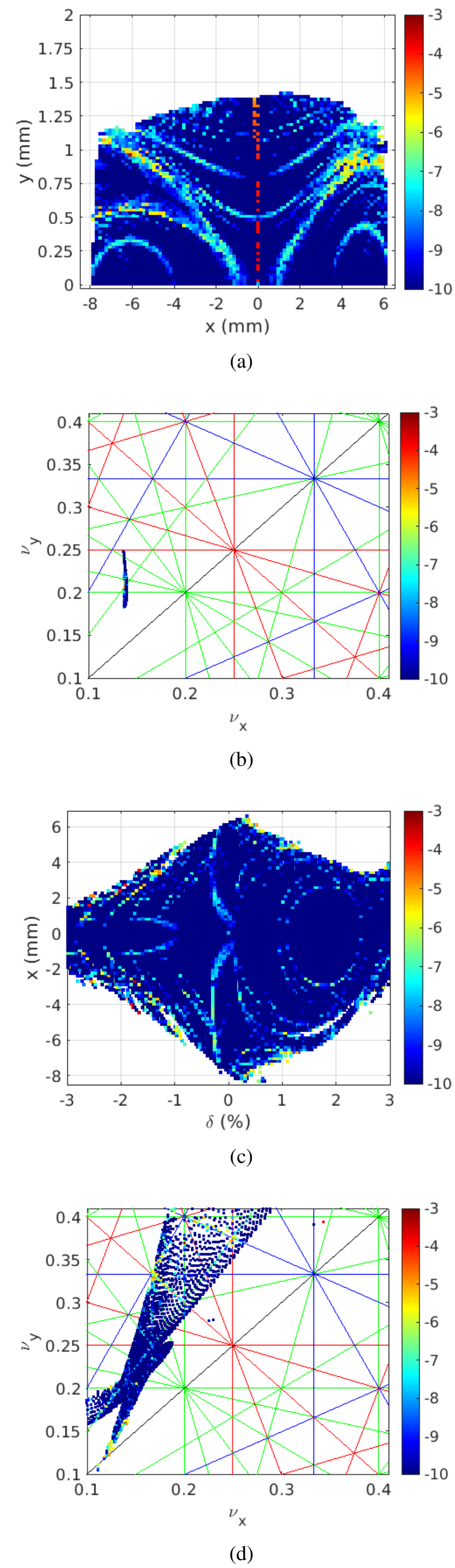

Figure 5: On (a,b) and off (c,d) energy dynamic aperture and corresponding frequency map. Tracking was performed including physical apertures but without the septum plate.

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Based on the proposed aperture sharing injection scheme for the Diamond-II ring, the septum magnet is positioned −6 mm from the stored beam [2]. A thin aperture element with ±6 mm half-gap is inserted in the centre of the injection straight to simulate the septum aperture.

To evaluate the performance of the ring including the injection cell, realistic focusing and alignment errors including higher order multipoles have been applied to the ring. The DA at the injection point for the baseline lattice and for the high-beta lattice with and without the septum aperture are shown in Fig. 6. Calculations were performed using 6D particle tracking for 20 error seeds. As shown in red, a substantial improvement in the DA is seen for the high-beta lattice. The DA has improved by more than 2 mm in the horizontal and by around 0.4 mm in the vertical direction for this case. However, once the septum aperture is included, the DA shown in black in Fig. 6 is limited to the physical septum aperture at −6 mm. Only a marginal increase in the horizontal plane is found for the high-beta lattice compared to the baseline lattice.

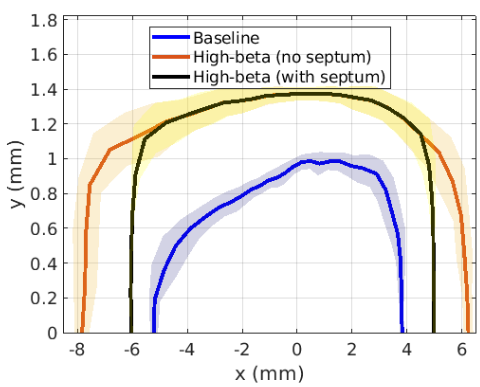

Figure 6: On energy dynamic aperture.

To evaluate the impact on the the injection efficiency (IE), Gaussian distributions of 1000 particles with an energy of 3.5 GeV, natural emittance of 17.7 nm, 10% coupling and a bunch length of 11.61 mm coming from the booster ring (BR) [1] are tracked at increasing amplitudes from the nominal orbit. Tracking results are displayed in Fig. 7. As expected, the larger DA in the high-beta lattice without the septum aperture improves the margin of safety for high IE by 1.5 mm, however, once the septum is taken into account the gain is reduced to 0.5 mm.

The momentum aperture (MA) for one super-period of the storage ring for each case is shown in Fig. 8 and the corresponding Touschek lifetimes are given in Table 3. The RF voltage, harmonic number, vertical emittance and charge per bunch are set to 1.42 MV, 934, 8 pm and 0.6 nC respectively. The resulting bunch length is 3.73 mm.

Despite the larger on-momentum DA for the high-beta lattice, Fig. 8 indicates a shrinkage of the momentum aperture resulting in a reduction in Touschek lifetime of approximately 24.7%.

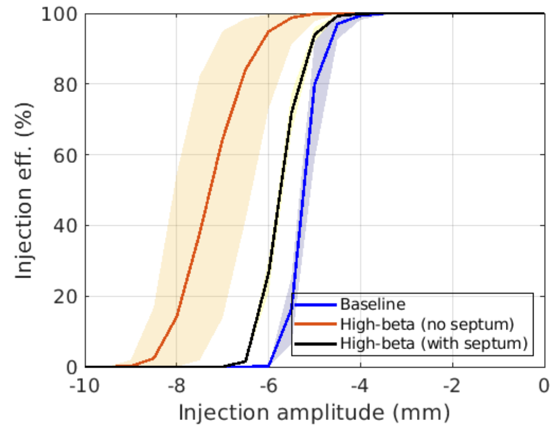

Figure 7: Injection efficiency versus injection amplitude.

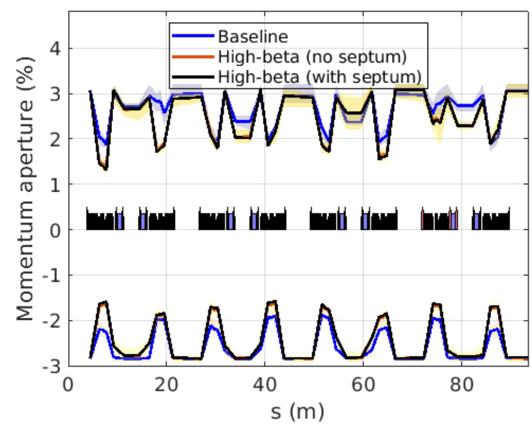

Figure 8: Momentum aperture for one super-period of the ring.

Table 3: Touschek Lifetime

	Touschek LT (h)
Baseline	2.23±0.13
High-beta (no septum)	1.72±0.05
High-beta (with septum)	1.68±0.05

CONCLUSION

The Diamond-II lattice performance with increased beta functions in the injection cell has been investigated. The results reveal that the DA and margin of safety for the IE can be improved by half a millimeter at the cost of a 24.7% reduction in the Touschek lifetime.

The main potential use of this lattice is in the early commissioning stages to enable first-turns and beam capture before optics correction has been applied. It also provides a fall-back option in case the injection efficiency during aperture-sharing is lower than anticipated. The same technique can be applied to alternative high-brightness lattices with lower emittance or improved matching of the beta-functions at the IDs to improve the performance.

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[2] J. Kallestrup, H. Ghasem, and I. P. S. Martin, "Aperture Sharing Injection for Diamond-II", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 2606–2609. doi:10.18429/JACoW-IPAC2022-THPOPT018