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TUNABILITY AND ALTERNATIVE OPTICS FOR THE DIAMOND-II STORAGE RING

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Abstract

When defining the magnet specifications, a key consideration is that the hardware should be flexible enough to allow some contingency for future tuning requirements or for alternative lattice solutions to be implemented. To define the required tunability of the magnets, we have investigated two lattice solutions for the Diamond-II storage ring upgrade, one with reduced beta functions at the straight sections for improved matching to the photon beam and one with an ultra-low emittance of 87 pm with IDs. In this paper, the linear and nonlinear beam dynamic issues as well as the photon beam brightness for these two options will be presented and discussed.

INTRODUCTION

In order to define the required tuning ranges and specifications for the different magnet types a number of investigations have been carried out. These include:

- Scanning the fractional tune point within the cell Q_x = 54 to 55 and Q_y = 20 to 21 whilst maintaining the phase advance constraints and nominal chromaticity.
- Keeping the fractional tune point constant but stepping the horizontal tune in integer units from 54.2 to 62.2, maintaining the phase advance constraints and nominal chromaticity.
- Increasing the chromaticity in integer steps from [+2, +2] to [+10, +10] at fixed tune point.
- Running MOGA optimisations with a variety of constraints and variable parameters, including adjusting the Twiss parameters at the sextupole or ID locations, altering the phase advance constraints and reconfiguring the sextupole families and allowing the chromaticity to vary.

The results of these investigations were used to develop the individual magnet designs, including altering the magnet lengths to either free-up space or keep peak gradients within practical limits.

An important principle when considering alternative optics is that the reference trajectory for the electron beam must remain fixed to avoid shifting the beamline source-points or altering which parts of the vacuum chamber are illuminated by synchrotron radiation. The consequence of this is that, if different optics were to be implemented at a later stage that involved changing the gradients in the anti-bends, the transverse offsets of the anti-bend (AB) magnets would need to be adjusted in proportion to the change in gradient to keep the bend angle constant. The OPA [1] and ELEGANT [2] codes have been employed for the optimizations. The final magnet strength limits adopted for the magnet specifications and imposed on the lattice tuning studies are given in Table 1.

Table 1: Magnet Strength Limits Used for Magnet Designs and During Lattice Optimisation Studies

Magnet	Parameter	Max. Value
Quadrupole	Gradient (T/m)	90
Anti-bend (high-gradient)	Gradient (T/m)	80
	Offset range (mm)	2.5 to 3.6
Anti-bend (low-gradient)	Gradient (T/m)	60
	Offset range (mm)	3.4 to 7.8
Skew-quadrupole	Gradient (T/m)	2.0
Sext. (narrow bore)	Gradient (T/m^2)	5000
Sext. (wide bore)	Gradient (T/m^2)	3500
Octupole	Gradient (T/m^3)	70000
Hor./Ver. corr.	Bend angle (mrad)	1.0
Hor./Ver. fast corr.	Bend angle (mrad)	0.02

LINEAR BEAM DYNAMICS

An illustration of the tunability of the lattice is given by the two alternative solutions shown in Fig. 1.

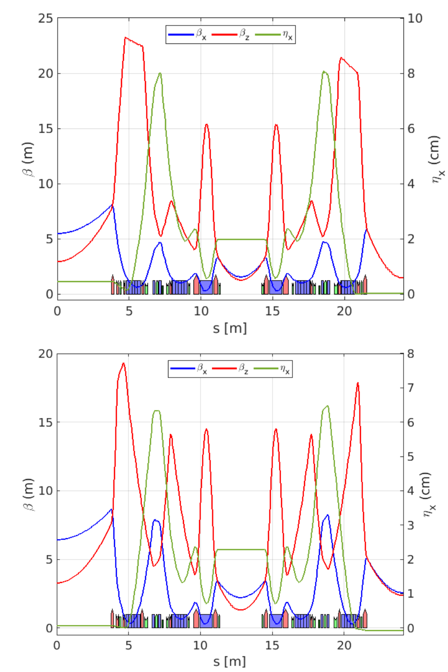

Figure 1: Optical functions in a unit cell, low beta (top) and low emittance (bottom) optics.

The first of these (referred to as the low beta solution) shows an optimisation where the beta functions at the ID source points have been reduced to give a better matching of the electron beam phase space to the intrinsic photon beam size and divergence, thereby increasing the brightness. In the second solution (referred to as the low emittance solution) the horizontal tune point has been further

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increased to give a reduction in the equilibrium emittance. To have a robust nonlinear beam dynamic performance, 3π and π radians phase advance between the focussing chromatic sextupoles across the mid straight section have been maintained in both solutions (the '-I transformer'). The main parameters of the lattices are given in Table 2.

Table 2: Main Parameters of the Different Lattice Alternatives

Parameter		Base line	Low β	Low ε
Horizontal tune		54.15	58.14	62.18
Vertical tune		20.27	21.27	20.30
Emittance (pm)		161.7	152.2	105.8
En. spread (%)		0.094	0.093	0.091
Emittance + IDs (pm)		121.1	114.9	86.5
En. spread + IDs (%)		0.108	0.108	0.108
Mom. Comp. ($\times 10^{-4}$)		1.04	1.11	0.96
Hor. Chromaticity		-67.6	-68.4	-90.4
Ver. Chromaticity		-88.5	-113.7	-112.4
β_x (m)	Long str.	8.21	5.53	6.45
	Stand. str.	5.53	1.50	2.58
	Mid. str.	2.26	1.60	2.24
β_y (m)	Long str.	3.50	2.99	3.30
	Stand. str.	2.32	1.50	2.39
	Mid. str.	1.68	1.30	1.32
η_x (mm)	Long str.	5.6	4.8	0.8
	Stand. str.	0.6	0.5	-0.6
	Mid. str.	22.0	20.0	22.9

NONLINEAR BEAM DYNAMICS

After correcting the natural chromaticity to around +1.5/+1.5 in both solutions, the driving terms were minimized to help control the tune shift with energy and amplitude and to provide largest dynamic aperture (DA) and momentum aperture (MA). The on/off energy DA at the centre of the long straight section (LSS) and corresponding frequency map (FM) are given in Fig. 2 for the low beta and in Fig. 3 for the low emittance lattice alternatives respectively. Afterwards, 6D tracking was conducted including radiation emission, the RF cavity, and the physical apertures for 20 seeds of errors. The resulting DAs are displayed in Fig. 4. In comparison with the base line lattice (please see Ref. [3, 4]) and as can be expected, there is a clear reduction in the dynamic aperture as the horizontal tune point is increased. A comparison of the momentum aperture between the lattices is shown in Fig. 5. As with the dynamic aperture, there is a clear reduction in momentum acceptance when moving between the lattices. This is also reflected in the lifetime calculations given in Table 3.

Table 3: Lifetime Related Parameters for Different Lattice Alternatives, Without IDs

Parameter	Base line	Low β	Low ε
RF voltage (MV)	1.42	1.25	1.25
Bunch length (mm)	3.74	4.22	3.82
Touschek Lifetime (h)	2.00	0.60	0.59

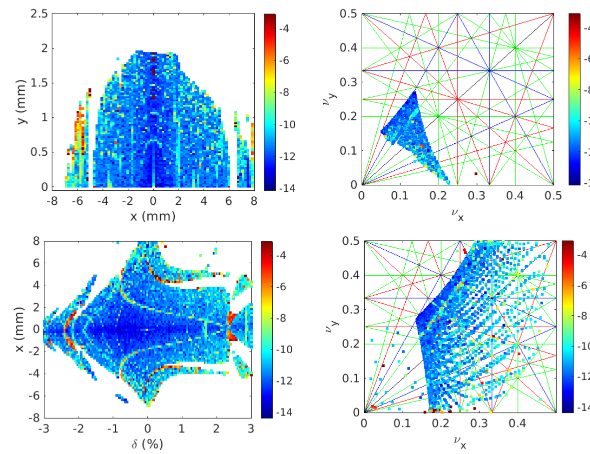

Figure 2: (top) on-momentum, (bottom) off-momentum, DA (left) and corresponding FM (right) in the low beta lattice.

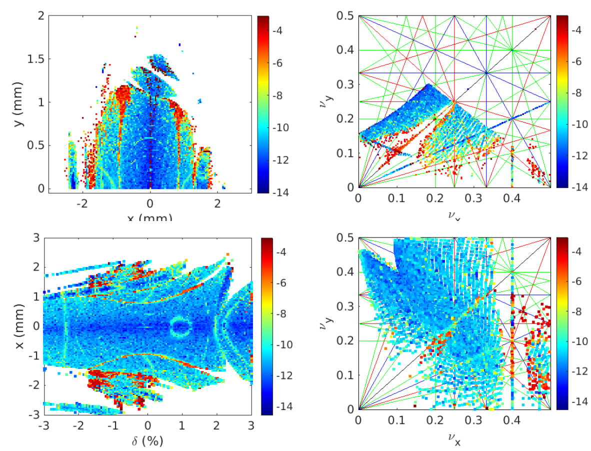

Figure 3: (top) on-momentum, (bottom) off-momentum, DA (left) and corresponding FM (right) in the low emittance lattice.

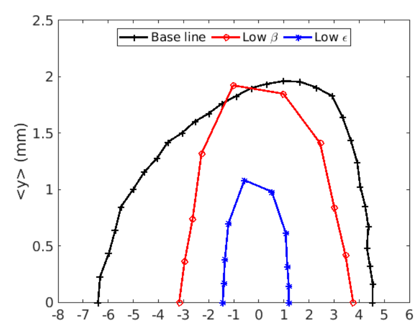

Figure 4: The mean on-momentum dynamic apertures at the centre of the long straight section.

A systematic study of to what extent either option would affect the brightness has been carried out. Three different IDs placed in Long, Mid. and Standard straight sections (LSS/MSS/SSS) have been studied to evaluate the radiation brilliance from IDs in these lattices. The main ID parameters used for calculating the radiation properties are given in Table 4 and the corresponding brilliances up to third harmonic are displayed in Fig. 6.

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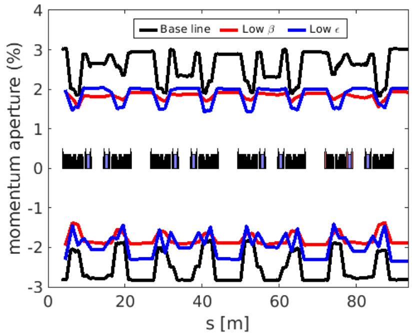

Figure 5: The mean momentum apertures for one super period of the ring.

Table 4: ID Parameters Used for Brightness Calculations

Parameter	**ID at MSS**	**ID at SSS**	**ID at LSS**
Length (m)	1.54	1.99	1.99
Period length (mm)	19.70	17.60	18.4
No. of period	78	113	108
Gap (mm)	4	4	5
K	2.24	2.30	2.09
B field (T)	1.22	1.40	1.22

As shown in Fig. 6, the radiation brilliance coming from an ID in the MSS in the low beta lattice is almost the same as from the same ID in the low emittance lattice and represents an increase of 20% compared to the base line lattice. Substantial radiation increase is seen from IDs in the standard straight section for both options. An ID in the SSS has an increase in brilliance of a factor 2 in the low beta lattice and an increase of 70% in the low emittance lattice. For the case of an ID in the LSS, there is a 20% increase in the radiation brilliance in the low beta option and a 35% increase from the same ID in the low emittance lattice. The brilliance curves were calculated using SPECTRA [5].

SUMMARY AND CONCLUSION

Optimisation of the low beta and low emittance lattices is ongoing work, with further improvement in dynamic aperture and lifetime desirable. At this stage, no in-depth analysis of either option has been completed, but it is considered unlikely that either option could reach the performance of the base line lattice. To cope with the smaller DA, an injection scheme based on enhanced aperture-sharing [6] has been studied and the results reveal that efficient beam injection would be achievable in the low beta solution. A swap out injection will be necessary for the low emittance lattice alternative. As such, options such as these are only being considered for a future 'brightness' upgrade for Diamond-II. This would allow the performance of the upgraded injector complex to be established beforehand and would only be considered after a reasonable period of routine user operation with base line lattice has been completed.

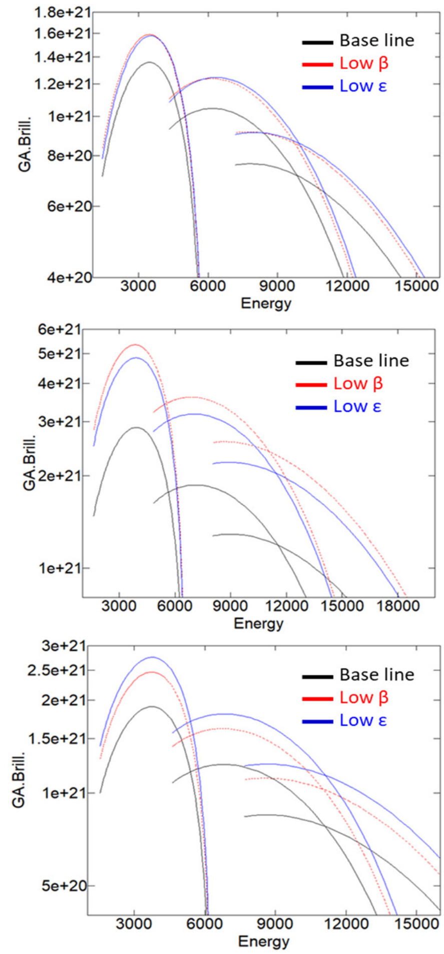

Figure 6: Radiation brilliance from typical IDs, at mid straight section (top), at standard straight section (middle) and in the long straight section (bottom).

REFERENCES

[1] A. Streun, OPA Lattice Design Code. https://ados.web.psi .ch/opa/

[2] M. Borland, "elegant: a flexible sdds-compliant code for accelerator simulation", Advanced Photon Source, Argonne National Laboratory, USA, Report No. LS-287, 2000. https://aps.anl.gov/sites/www.aps.anl.gov/files/APS-sync/lsnotes/files/APS_1418218.pdf

[3] "Diamond-II Technical Design Report", Diamond Light Source, to be published. https://www.diamond.ac.uk/Home/About/Vision/Diamond-II.html

[4] H. Ghasem, I.P.S. Martin, B. Singh, "Progress with the Diamond-II storage ring lattice", in *Proc. IPAC'21*, Campinas, SP, Brazil, May 2021, pp. 3973-3976. doi:10.18429/JACoW-IPAC2021-THPAB090

[5] T. Tanaka and H. Kitamura, "SPECTRA: a synchrotron radiation calculation code", *J. Synchrotron Radiat.*, vol. 8, p. 1221, Nov. 2001. https://doi.org/10.1107/S090904950101425X

[6] J. Kallestrup *et al.*, "Aperture Sharing Injection for Diamond-II", presented at the 13th International Particle Accelerator Conference (IPAC'22), Bangkok, Thailand, June 2022, paper THPOPT018, this conference.