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FURTHER INVESTIGATIONS INTO THE IMPACTS OF INSERTION DEVICES ON THE DIAMOND-II LATTICE

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Abstract

As part of the Diamond-II upgrade project, the Diamond storage ring will be replaced with a new modified hybrid 6 bend achromat (M-H6BA) lattice, in which each existing arc section will be split in two to provide additional mid-straights and thereby increase the ring capacity. Most insertion devices (IDs) currently in operation will be either retained or upgraded, and the new mid-straights allow the total number of ID beamlines to be increased from 28 to 36. Therefore, it is important to investigate how the IDs will affect the equilibrium emittance and energy spread, along with their impact on the linear and nonlinear beam dynamics. Methods to compensate for their effects have been established, including a re-optimization of the octupole settings and identification of alternative working points. The impact of IDs on a lattice with high βx in the injection cell for better injection efficiency has also been studied. A kickmap approach has been used to model all IDs, including the APPLE-II IDs and APPLE-Knot with active shim wires. In this paper, the outcome of these investigations will be presented.

INTRODUCTION

There will be 8 additional ID beamlines in the Diamond-II upgrade compared to the number in the existing Diamond storage ring. Some of the existing IDs are to be upgraded while others will be retained. Investigations into the impact of the IDs on Diamond-II performance have been underway for some time, with first results reported in reference [1] and recent updates to be reported in this paper. The APPLE-knot ID for the I05 beamline has had several design versions [2, 3], and a final version has now been selected. This will be installed in Diamond-II only. It has further been decided to use active shims for all three APPLE-types undulators located in the long straight sections, as investigations into their performance demonstrated they cause significant optics degradation to the Diamond-II lattice. The recovery of optics distortions from these IDs could in principle be achieved using LOCO corrections, as this recovers the lifetime and injection efficiency required for operation. However, this method is difficult to implement in practice for IDs with frequent gap and phase changes.

Optimisation of the Diamond-II storage ring was originally based on the use of -I transformers between the strong chromatic sextupoles, cell tunes satisfying higher-order achromat conditions and maintaining 24-fold pseudo-symmetry [4]. As such, degradation of the nonlinear dynamics is mainly caused by symmetry breaking. The major contributors to this are the super-conducting wigglers (SCWs). The final ID compensation strategy is to apply a LOCO correction for the SCWs are set to full field (after LOCO), then to use tune feedback for all other IDs, as demonstrated and reported in [1]. Further investigations revealed that the I05 APPLE-Knot ID and the I17 and I21 APPLE-II undulators in vertical polarization mode at minimum gap cause the most severe symmetry breaking, leading to degradation of the on-momentum dynamic aperture (DA) and momentum aperture and ultimately to a drop in lifetime and injection efficiency. The use of active shims in these long straight sections was found to be sufficient to recover machine performance, along with application of the tune feedback.

INVESTIGATIONS WITH ALL IDS

The impact of IDs on the Diamond-II lattice has been studied using AT2 and the kickmap approach, as described in [1]. In the studies, all IDs are assumed to be closed to minimum gap and the SCWs are set to full field (after LOCO). The I05, I17 and I21 APPLE IDs are included in vertical polarisation mode, which is considered to be the most disruptive condition, but with active shim wire compensation applied.

The residual beta-beat in this case is shown in Fig. 1. It is less than 10% in both horizontal and vertical planes, except in the regions close to the SCWs.

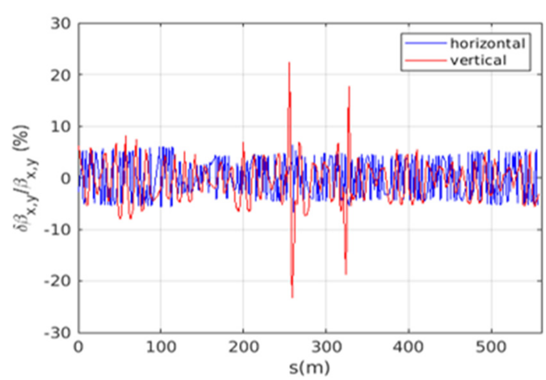

Figure 1: The residual beta-beat due to all IDs in upgrade lattice after LOCO of SCWs and a global tune correction.

In addition to distorting the linear optics (beta-beat) and breaking the lattice symmetries, IDs produce their own nonlinear effects and can impact the 6D DA. As such, Touschek lifetime and injection efficiency need to be simulated. This has been done using a 'reduced' error model [4] for five seeds and all with aperture limitations. The RF voltage is adjusted to maximise the lifetime, including ID energy loss. The vertical emittance has been fixed at 8 pm

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rad, the bunch charge is 0.6 nC and the natural bunch length of 3.6 mm has been assumed. The injection efficiency has been calculated for 1000 particles and 2500 turns. The injection offset has been deliberately increased from the nominal -4 mm to -4.5 mm to account for mis-steers. The results for the 6D DA are shown in Fig. 2 and lifetime and injection efficiency are reported in Table 1 for collimators closed. More details can be found in reference [4].

Table 1: Impact of IDs on Touschek Lifetime and Injection efficiency

Case	Touschek lifetime [h]	Injection Efficiency (%)
All IDs (with corrections)	2.05±0.04	86.2±2.0
Bare (No IDs)	2.24±0.06	98.2±0.47

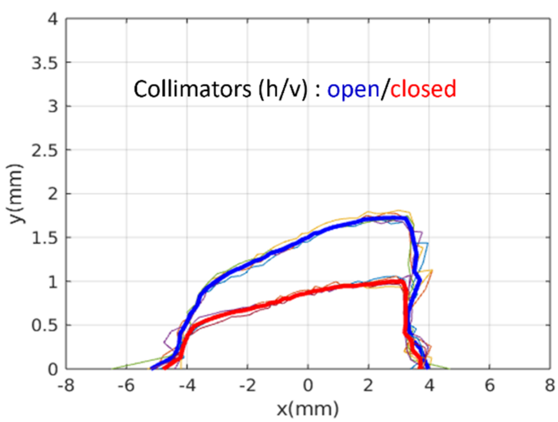

Figure 2: Dynamic aperture (6D) including all IDs after optics correction for 5 error seeds and with all aperture limitations and collimators open (blue) and closed (red). The dynamic apertures are calculated at the centre of the long straight.

FURTHER OPTIMIZATION

Further investigations have been carried out to see if the Touschek lifetime and injection efficiency can be improved by optimizing the octupole strengths or by changing the working point of the machine.

Optimisation of Octupole Strength

A second octupole family (O0X) has been added to the Diamond-II storage ring since publication of the TDR. These are located at the ends of the long straight sections where dispersion is small. The amplitude-dependant tunes can be manipulated using these magnets, including the effect of the IDs. The rms lifetime (Touschek) and rms injection efficiency for five errors seeds as a function of O0X octupole strength are shown in Fig. 3. The marker 'a' in the figure corresponds to the value optimised for the bare lattice while marker 'b' corresponds to the best lifetime with high injection efficiency. The results are summarised in Table 2. The new octupole settings 'b' is found to improve the performance of the machine and are now the default values. The primary octupole family (O1X) was left unchanged from the value found for the bare lattice.

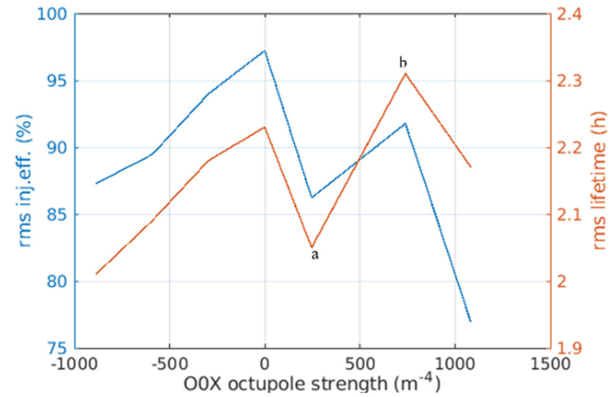

Figure 3: The rms lifetime (Touschek) and rms injection efficiency for 5 error seeds in presence of all IDs after optics correction verses O0X octupole strength. Nominal value and optimized new value are represented by 'a' and 'b' respectively.

Table 2: Impact of IDs on Touschek Lifetime and Injection Efficiency for Optimised O0X octupole value with All IDs closed

Case	Touschek lifetime [h]	Injection Efficiency (%)
New ('b')	2.31±0.03	91.9 ± 1.5
Nominal ('a')	2.05± 0.04	86.2 ± 2.0

Optimization of Working Point

The working point (betatron tune) has been further optimized by scanning the value and calculating rms lifetime and injection efficiency over 5 reduced error seeds after correcting orbit and chromaticity at each point. The O0X octupole family was fixed at the 'b' values through the study. The results of the tune scans for lifetime and injection efficiency are shown in Fig. 4 and Fig. 5 respectively.

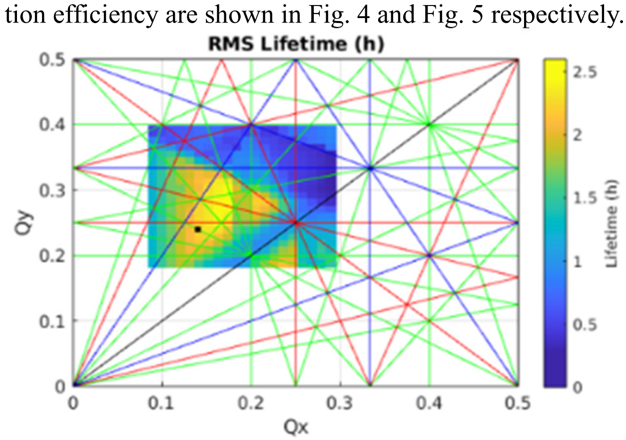

Figure 4: The rms Touschek lifetime simulated for 5 error seeds verses betatron tunes in presence of all IDs after optics correction. The nominal tune is shown as a black dot [54.14, 20.24].

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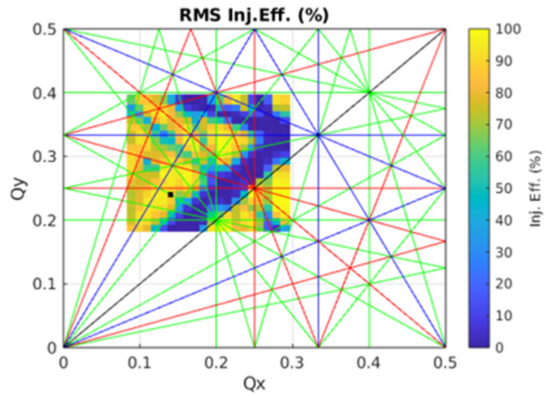

Figure 5: The rms injection efficiency simulated for 5 error seeds verses betatron tunes in presence of all IDs after optics correction. The nominal tune is shown as a black dot [54.14, 20.24].

The results show it is difficult to achieve good lifetime and good injection simultaneously. The tune point [54.165, 20.265] looks to have improved lifetime (~2.4h) with similar injection efficiency.

LATTICE WITH HIGH BETA-X INJECTION STRAIGHT

A version of the Diamond-II lattice with high β_x in the injection straight is described in reference [5]. In this section we investigate how IDs impact the performance. The same procedure is adopted for compensating for the IDs as described above. The on-momentum DA, horizontal DA verses dp/p, lifetime and injection efficiency have all been calculated. Results are shown in Figs. 6 and 7 and Table 3. Adding IDs is found to have negligible impact on the performance of this lattice.

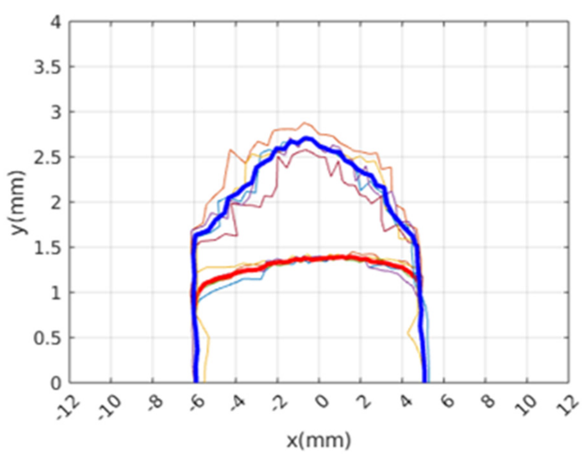

Figure 6: On-momentum DA calculated for five error seeds with all IDs after optics correction at the middle of the high β_x injection straight with all apertures including septum at ±6 mm in horizontal. Thick lines show the mean over 5 error seeds and collimators closed (red) and open (blue).

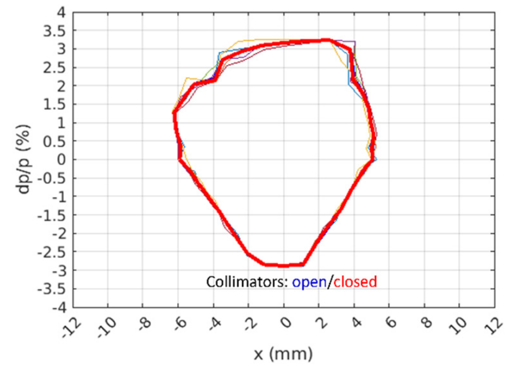

Figure 7: Horizontal DA verses dp/p (%) calculated for five error seeds with all IDs after optics correction at the middle of the high β_x injection straight with all apertures including septum at ±6 mm in horizontal. Thick lines show the mean over five error seeds and collimators closed (red) and open (blue).

Table 3: Impact of IDs on Touschek Lifetime and injection efficiency for the high βx injection straight Diamond-II lattice version with all apertures and with collimators closed.

Case	Touschek lifetime [h]	Injection Efficiency (%)
All IDs (with corrections)	1.77±0.02	98.1±0.4
Bare (No IDs)	1.73±0.03	100.0±0.1

CONCLUSIONS

The number of IDs to be operated in Diamond-II increases to 36 and it is important to assess their impacts on machine operations. A correction procedure has been developed after extensive studies. LOCO correction can be performed for the super conducting wigglers (SCWs) as these are static devices. Active shims are to be employed for the three APPLE-II undulators located in long straight sections (I05, I17 and I21). For all other IDs a global tune correction is applied. This leaves residual beta beat less than 10% and with a Touschek lifetime of 2.05h and injection efficiency about 86%. The performance can be improved by tuning the O0X octupole family, resulting in a lifetime of 2.31h and injection efficiency of 92%. The injection efficiency has been calculated for 4.5 mm injection offset compared to the 4 mm design value. After adjusting O0X, the impact of IDs can be considered negligible. Further improvement can be achieved by adjusting the working point of the machine.

In case a higher on-momentum DA is required for better injection, the lattice version with high β_x injection straight can employed. This has high injection efficiency of 98% at 4.5 mm offset with IDs but a smaller lifetime of 1.77h due to the break of machine symmetry. It can be used if there is problem during the commissioning stage.

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