ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPJE061

INJECTION STUDIES FOR THE DIAMOND STORAGE RING

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Abstract

The Diamond storage ring will be upgraded during 2016 by replacing one of the existing double bend achromat (DBA) cells with a double-DBA (DDBA) cell [1]. It is anticipated that both the on and off momentum dynamic aperture will reduce as a result of this change. In order to prepare for this eventuality, injection into the Diamond storage ring has been recently studied in detail. In particular, the oscillation amplitude, angle and energy of the injected beam have been determined, along with the position of the stored beam with respect to the septum plate. Following these studies, the injected beam energy has been matched to the storage ring, and plans have been put in place to move the injection septum 4 mm closer to the stored beam centre line.

INTRODUCTION

The Diamond storage ring will be upgraded in August 2016 by replacing one of the existing DBA cells with a single DDBA cell [1]. The primary goal of this exercise is to increase the capacity for insertion device beamlines; however, the extensive design and engineering work involved also serves as a good basis from which to proceed towards a full low emittance upgrade of the entire storage ring [2].

When developing the upgrade lattice, the main focus has been on retaining the existing Twiss parameters at the ID source points, whilst at the same time minimising the impact of the upgrade on the lifetime and injection efficiency. At present it is anticipated the lifetime will drop by ~10% to 15%, with a similar drop in the injection efficiency [3]. A low-alpha lattice solution is also being developed in parallel to this work [4]. In this case the impact on the on- and off-momentum dynamic aperture is more dramatic, reducing the injection efficiency to close to zero (assuming the existing injection parameters).

In order to combat this reduction in injection efficiency, it has been proposed to reduce the separation between stored and injected beams from the existing 8.3 mm. This reduction could in principle be achieved by moving the stored beam closer to the septum plate by increasing the amplitude of the injection kicker magnets, or alternatively by applying a static orbit bump across the straight using the dipole corrector magnets embedded in the sextupoles. However, the preferred solution is to move the septum magnet from the existing position of -16 mm offset from the stored beam centre line to -12 mm offset. This has the advantage that the kicker magnets can then be run at a lower field (thereby reducing the disturbance to the stored beam during top-up injection cycles), and also allows for single-shot on-axis injection (forming part of the DDBA commissioning plan).

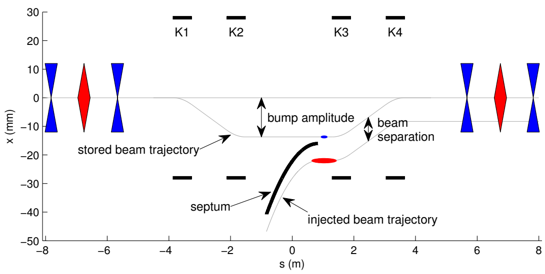

Figure 1: Injection schematic for the Diamond storage ring.

INJECTION SCHEME

Injection into the Diamond storage ring is carried out within a single long straight section. The scheme uses four pulsed kicker magnets to bump the stored beam towards the septum magnet, with the injected beam arriving at a nominal displacement of -8.3 mm from the stored beam. A schematic of the injection process is shown in Fig. 1, and the main parameters are given in Table 1.

The nominal beam separation was decided upon during the design phase after assuming highly pessimistic values for the stored and injected beam emittances, alignment tolerances on the septum plate and shot-to-shot variability in the injected beam trajectory. In principle, the separation could be reduced to the absolute minimum value of $3\sigma_{stored}$ + $3\sigma_{inj}$ + septum thickness = 5.8 mm. However, this would leave no contingency for trajectory or transient closed orbit errors due to non-closure of the kicker bump.

Table 1: Injection Parameters

Parameter	**Value**
Nom. injected beam size (1σ)	0.69 mm
Nom. stored beam size (1σ)	0.18 mm
Nom. septum displacement (inside edge)	-16 mm
Septum thickness	3.2 mm
Nom. bump amplitude	-13.7 mm
Max. bump amplitude	-18.8 mm
Nom. stored/injected beam sep.	8.3 mm
Storage ring revolution period	1.87 μs
Kicker pulse duration (half sine)	6 μs

MEASUREMENTS

In order to set a realistic limit on the minimum achievable stored and injected beam separation, studies have been made on the impact of various parameter changes. At the same time, investigations were carried out to identify potential detrimental effects resulting from the septum move.

6th International Particle Accelerator Conference IPAC2015, Richmond, VA, USA JACoW Publishing
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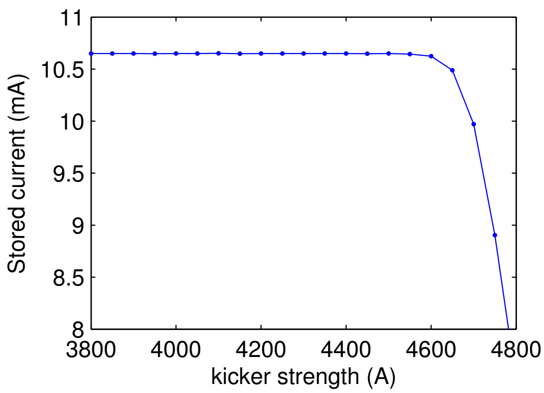

Figure 2: Stored current vs. injection kicker amplitude.

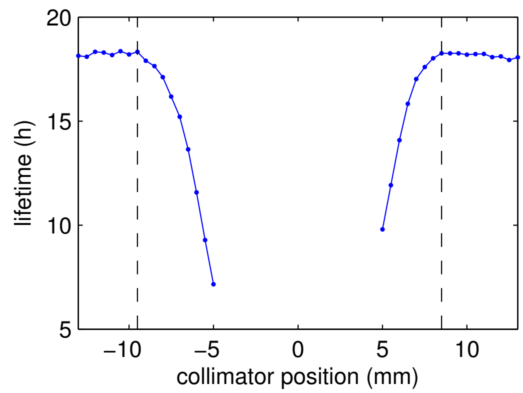

Figure 3: Lifetime vs. horizontal collimator aperture. The dashed vertical lines indicate the point at which the collimators begin to affect the lifetime.

Stored Beam Studies

The potential for reducing the separation was investigated by increasing the amplitude of the kicker bump. This was done by filling the storage ring with 10 mA in a full-filling pattern and increasing the amplitude of the bump until the stored beam began to hit the septum plate (see Fig. 2). This began to happen at 4550 A, corresponding to a bump amplitude of 15.9 mm according to the kicker calibration data.

The septum magnet is designed to be moved parallel to the booster-to-storage ring transfer line axis. As such, any movement will primarily affect the stored beam, with negligible difference for the injected beam. Since the amplitude of the kicker bump can be adjusted, the main impact will be a reduction in the horizontal aperture and a potential lowering of the lifetime.

To investigate this possibility, the reduction in aperture was simulated by moving in the horizontal collimator blades. These are located in the injection straight after kicker 4 where $\beta_x = 11.3$ m ($\beta_x = 9.8$ m at the exit of the septum). The standard collimator settings are ±12 mm, which when scaled with β_x already limit the horizontal acceptance more than the septum would at -12 mm offset. The results of the lifetime vs. collimator aperture scan are shown in Fig. 3. From this it can be concluded that moving the septum in to -12 mm will not affect the lifetime.

Injected Beam Studies

The impact of reducing the beam separation on the injected beam was also investigated by increasing the amplitude of the kicker bump. It was anticipated that the injection efficiency would initially increase, up to the point where either the stored or injected beam begins to hit the inside edge of the septum plate. Before starting the measurement, insertion device gaps were opened and the transfer line corrector magnets were optimised to ensure the injected beam is already as close to the outside edge of the septum plate as can be achieved without beam loss. Results are shown in Fig. 4. Note that the >100% injection efficiency is due to an ICT calibration error, and the cyclic variation results from small variations in the dynamics of filling different slots in the storage ring. Figure 4 shows a sharp drop in the injection efficiency at 4550 A, consistent with the amplitude at which the stored beam begins to hit the septum plate.

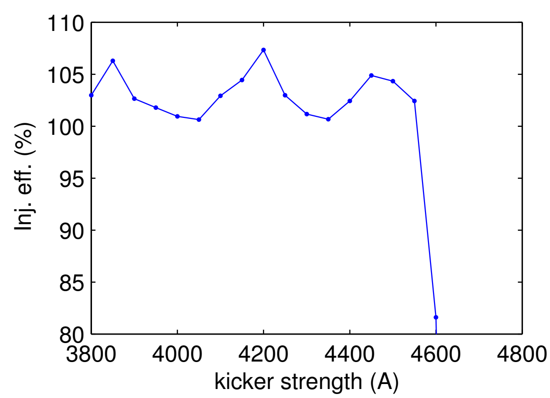

Figure 4: Injection efficiency vs. kicker amplitude.

The first-turn trajectory of the injected beam can be accurately measured using the turn-by-turn BPM data (after accounting for BPM gain, roll, geometric non-linearities and frequency response, see [5]). This can then be compared to particle tracking data in order to reconstruct the initial values at the exit of the septum. Measurements of this type were performed twice, once with the kickers set to the nominal 3800 A and once with them at 4550 A. The measurements were taken in multibunch mode, with the charge per pulse maximised in order to ease the requirements on the diagnostics. The RF cavities were powered off, both to prevent beam capture and to prevent leaking of the RF field into the adjacent BPMs. Results are shown in Fig. 5, and the fitted values for injected beam trajectory and energy are given in Table 2.

For both 3800 A and 4550 A operation, Fig. 5 shows there is good agreement between measured and reconstructed injected beam trajectories. The existing kicker settings lead to an initial amplitude close to the design value of -8.3 mm, and the data taken at 4550 A indicate it should be possible to reduce the beam separation close to the theoreti-

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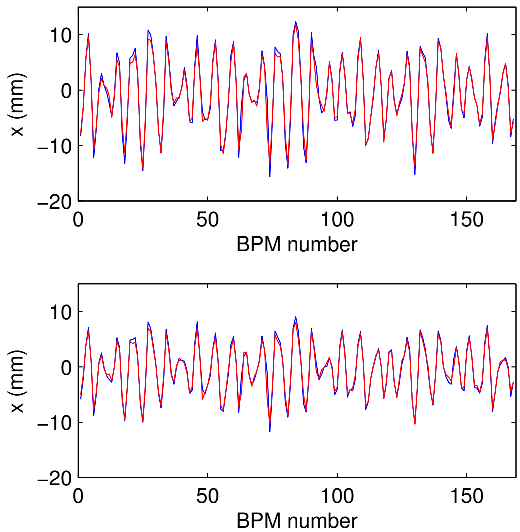

Figure 5: Measured trajectory of the injected beam during the first turn of the storage ring (blue) compared to the reconstructed model trajectory (red). Top: Kickers at 3800 A. Bottom: Kickers at 4550 A.

Table 2: Injected Beam Fit Parameters

	3800 A	**4550 A**
Initial Position	-8.21 mm	-5.95 mm
Initial Angle	0.12 mrad	0.21 mrad
Energy Deviation	-0.33 %	-0.30 %

cal minimum value of 5.8 mm. The fitted value of -0.3% energy error was later confirmed by measuring the synchrotron oscillation amplitude and has subsequently been corrected.

In principle, the initial angle and displacement of the injected beam could also have been measured using the two YAG screens located after the septum and between kickers 3 and 4. However, attempts to do this proved inconclusive due to uncertainties on the absolute screen positions.

Injection Kicker Studies

Under the assumption that the septum is moved from -16 mm to -12 mm horizontal displacement, the kicker amplitudes will need to be reduced from 3800 A to 2650 A to keep the beam separation at 8.3 mm, or 3400 A for 5.9 mm separation. These values represent a non-trivial departure from the existing set-points, and may require an adjustment in order to guarantee stable operation.

To investigate this possibility, the performance of the kickers was measured between 1000 A to 5000 A. No significant change was observed in either pulse width or peak stability; however, the peak shifted in time by ~400 ns across the range. A plot showing the kicker pulse profiles as a function of current is shown in Fig. 6.

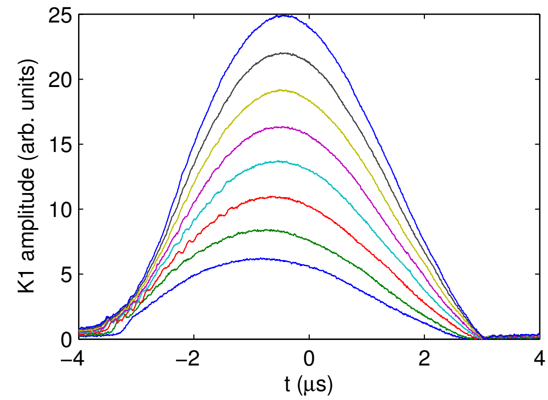

Figure 6: Kicker 1 pulses measured between 1000 A and 5000 A.

SEPTUM MOVE

The results presented in the previous section indicate there is significant leeway to reduce the beam separation from the design value of 8.3 mm towards the theoretical minimum value of 5.8 mm. At the same time, no adverse effect could be identified associated with the proposed movement of the septum magnet. As such, the decision was taken to move the septum from the design position of -16 mm offset to -12 mm offset.

An initial survey of the injection straight was carried out in November 2014, and following this a mock-up of the key components was constructed in order to study the mechanics of the move. This highlighted that small alignment errors for the pre and post-septum bellows would prevent the full movement of the septum vessel from taking place. As such, new bellows assemblies are in the process of being designed and manufactured, with the intention of completing the move in Summer 2015.

CONCLUSIONS

Injection into the Diamond storage ring has been systematically studied in preparation for the DDBA upgrade. These measurements established that the existing set-up is close to the design configuration, and that there is scope to reduce the separation of stored and injected beams by up to 2.5 mm. As a result, plans have been put in place to move the storage ring septum magnet 4 mm closer to the stored beam centre line. This move will relax the required dynamic aperture for injection into the DDBA lattice, allow the kickers to be run at lower field to reduce the disturbance of the stored beam during top-up, and allows for single-shot, on-axis injection to take place.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to A. Day and R. Howard for their efforts in modifying the septum vessel to allow the move to go ahead, and to G. Rehm for expert advice regarding the diagnostics used for these studies.

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