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INJECTION STUDIES FOR THE PROPOSED DIAMOND-II STORAGE RING

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Abstract

The baseline design for the Diamond-II storage ring consists of a Modified-Hybrid 6-Bend Achromat that combines the ESRF-EBS low-emittance cell design with the DDBA mid-straight concept [1–3]. This cell design provides sufficient dynamic aperture to permit an off-axis injection scheme, provided the emittance of the injected beam is sufficiently low. In this paper we present simulations of an injection scheme using the anti-septum concept [4, 5], along with the design of an upgrade to the existing booster synchrotron. Alternative injection strategies are also discussed.

INTRODUCTION

Diamond Light Source is in the process of designing a replacement storage ring, with the twin aims of lowering the emittance of the electron beam whilst increasing the capacity for insertion device beam-lines [1]. In common with other similar projects, the available dynamic aperture for this ring is substantially lower than for the existing ring, and so a range of possible injection schemes have been considered [2, 4, 6–12].

For the upgrade, an accumulation injection scheme is preferred over swap-out. This is to avoid the significant drop in brightness that occurs as the low emittance bunches are replaced by high emittance ones from the injector, and the need to install and operate a separate accumulator ring in the case of multi-bunch swap-out. Single bunch swap-out may be feasible, however, this would require 4 ns kickers of sufficient strength to be developed. At present, the proposed storage ring design does not provide enough momentum aperture for longitudinal injection schemes to be considered, meaning any accumulation must occur in the transverse plane.

The baseline injection scheme is therefore to use an 'anti-septum' magnet [4, 5], as originally proposed for the SLS-2 upgrade project [13]. This magnet has a thin 1 mm septum plate between the stored and injected beams, which in combination with a lowering of the emittance from the booster allows off-axis accumulation into dynamic apertures as small as ~4-5 mm. In this paper we describe the implementation of this scheme for the Diamond-II storage ring, along with an outline design for a replacement booster synchrotron.

STORAGE RING INJECTION

Injection Scheme

As shown in Fig. 1, the space available for the injected beam is limited. In the horizontal plane, the combined width of the stored beam, injected beam and anti-septum plate must be less than ~4 mm. At this amplitude, the momentum aperture is ±1%, which using the expected RF and storage ring parameters corresponds to a maximum injected bunch length of ~40 ps rms. In order to satisfy these constraints, a new booster synchrotron is required. A conceptual design for the new booster is presented in the next section, for which the equilibrium emittance at 3.5 GeV is 14 nm.rad.

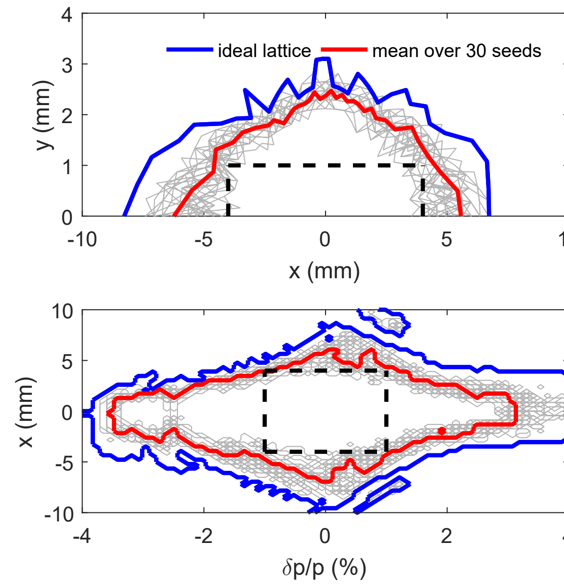

Figure 1: Impact of field and alignment errors on the on (top) and off (bottom) momentum dynamic apertures for the Diamond-II storage ring. The space available for the injected beam is highlighted in black.

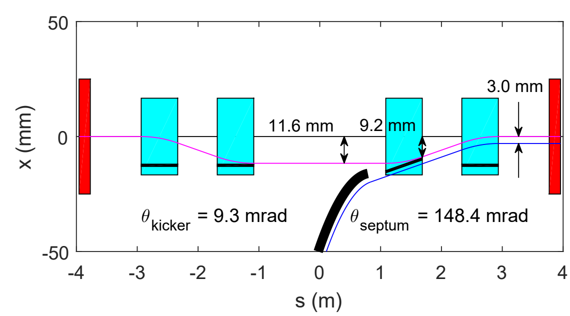

Figure 2: Diamond-II storage ring injection straight layout. Kickers are in cyan, quadrupoles are red and the septum / anti-septum plates are black curves.

The proposed layout of the injection straight is shown in Fig. 2. As with the existing injection scheme, the stored beam is bumped towards the main septum magnet using four half-sine kicker magnets (6 µs duration), with the injected electrons arriving at the peak of the orbit distortion. The

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bump amplitude decays to zero over the subsequent 1-2 turns. The main difference with the new scheme is that the third kicker magnet has an anti-septum insert inside the ceramic vessel [5], such that the injected beam is shielded from the kicker field and passes through the magnet un-deflected. Since the field in the kicker is much lower than in the main septum, the plate separating the stored and injected beams can be made very thin (assumed to be 1 mm).

The horizontal position of the anti-septum plate has been determined based upon a scaling of the vacuum vessel in the arc sections with the local β-functions, resulting in a 9.2 mm displacement from the stored beam centre-line. This in turn fixes the amplitude of the orbit bump (11.6 mm) and kicker bend angles (9.3 mrad), and also the incoming angle for the injected beam. Assuming the space allocated for the stored and injected beams is $10\sigma_s$ and $3\sigma_i$ respectively, plus an additional 1 mm allowance for alignment tolerances, beam drift and shot-to-shot jitter, the centre of the injected beam exits the injection straight 3.0 mm from the stored beam.

The viability of this injection scheme has been tested by tracking an injected bunch of 1000 particles at different initial amplitudes for 2048 turns (5.5 synchrotron periods). The results are shown for both with and without magnet field and alignment errors in Fig. 3. Assuming nominal injection parameters can be achieved, the simulation results indicate close to ~100 % injection efficiency can be expected.

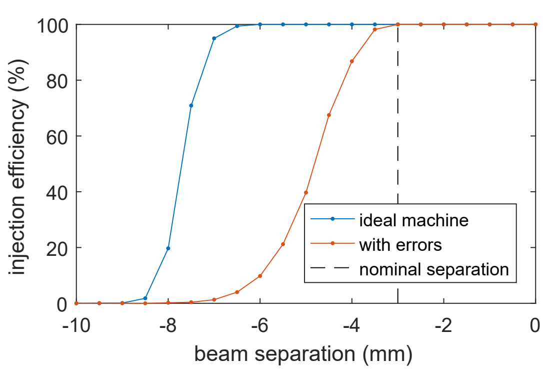

Figure 3: Injection efficiency as a function of beam separation assuming upgraded booster parameters, with and without field and alignment errors.

Top-up Considerations

One potential risk with injection schemes that shift the stored beam is that imperfect closure of the injection bump can cause disturbance to users' experiments. The impact of this may be exacerbated by the smaller beam sizes and by the shorter lifetime of the new ring, as a greater number of injection cycles will be required in order to maintain the same current stability. In order to minimise this risk, uniformity of all kicker power supplies and ceramic vessel coating will need to be ensured. Any residual beam oscillation can be suppressed by with-beam correction of the kicker magnet tilts [14] and by using dedicated compensation kickers [15], and gating signals will continue to be supplied to all beam-lines. Also, the number of shots fired per cycle can be reduced by increasing the charge per shot. This can be achieved either by using multi-bunch injection directly from the linac, or by allowing all single-bunch shots from the linac to be accumulated directly in the booster synchrotron and only transferred to the storage ring on the final shot.

Initial Commissioning

Commissioning of the storage ring is assumed to begin with single-shot, on-axis injection [16]. This can be achieved by a small adjustment of the trajectory of the beam exiting the transfer line, and by firing just the final kicker after increasing the bend angle. On-axis injection will greatly simplify initial commissioning of machine components, such as setting of the dipole and corrector bend angles to achieve first turns, calibration of the BPM centres and coping with a reduced, unoptimised dynamic aperture.

Alternative Injection Schemes

Whilst the above injection scheme appears to be a practical and viable solution for the upgrade, there are a number of potential areas in which it can be improved. The first idea under consideration is to replace the anti-septum magnet with a standard kicker and to use a combined thick/thin main septum magnet [8], in which the magnetic field in the final part of the magnet is lowered to enable a 1 mm septum plate. This solution may be simpler to design and construct and achieve a lower impedance, whilst still allowing a small separation between stored and injected beams.

Another alternative is to replace the four-kicker bump with a nonlinear kicker [7], as this would help to reduce the perturbation given to the stored beam during the injection cycle. The feasibility of this depends upon the acceptable vertical aperture of the magnet and hence the horizontal position of the peak magnetic field, as this determines how close the injected beam can be brought to the stored beam.

Lastly, single bunch swap-out injection remains under consideration. The key areas in this case are to assess the feasibility of constructing 4 ns kicker pulses of sufficient strength, how to deal with the depleted bunches removed from the ring, and whether suitable high-charge single bunches can be extracted from the booster.

NEW BOOSTER DESIGN

Design Considerations

The primary design goals for the replacement booster are that the extraction energy needs to be increased from 3.0 to 3.5 GeV, the emittance should be below ~20-30 nm.rad and the bunch length should be below ~40 ps rms. In addition, there are a number of practical constraints, such as the new ring must fit inside the existing booster tunnel, and the lattice design should provide large dynamic and momentum apertures to achieve high injection efficiency and long lifetime with respect to the top-up cycle. Other desirable features include being able to support accumulation and a low impedance to enable high current bunches to be accelerated.

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Booster Lattice

An outline design for a replacement booster was presented in [17]. The original proposal for this ring was to operate it as an accumulator ring around the outside of the existing booster, however, the same basic lattice structure can be applied to the new booster design. Further development work has been carried out on this lattice [1], resulting in the beam parameters listed in Table 1. The Twiss parameters for one super-period are shown in Fig. 4.

Table 1: Comparison of Booster Parameters

Parameter	Existing Booster	New Booster
Energy Range	0.1-3.0 GeV	0.1-3.5 GeV
Circumference	158.4 m	170.5 m
Betatron Tunes	[7.18,4.27]	[13.17,4.37]
Nat. Chromaticity	[-9.7,-6.3]	[-25.7,-10.1]
Emittance	134.4 nm.rad	13.9 nm.rad
En. spread	0.073 %	0.105 %
En. Loss Per Turn	0.58 MeV	1.64 MeV
Nat. Bunch Length	99.3 ps	41.1 ps

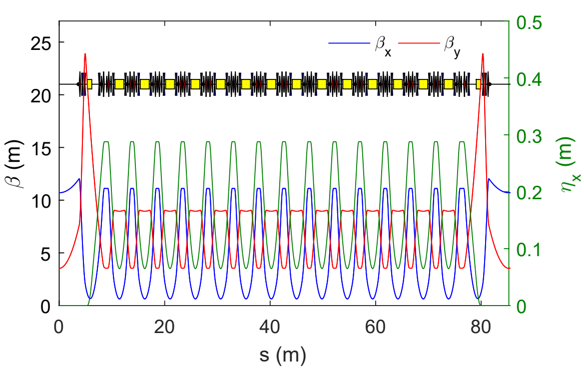

Figure 4: Twiss parameters for one super-period of the new booster design.

Correction of closed orbit distortions will be made using one BPM, one horizontal and one vertical corrector per unit cell, with additional BPMs and correctors at the ends of the straights and matching sections. No optics or coupling correction is envisaged, other than a global tune and chromaticity correction using the magnet families. To test the robustness of this strategy, numerous simulations have been conducted using realistic field and alignment errors. The on-momentum dynamic apertures for 50 such error seeds are shown in Fig. 5, indicating that ample dynamic aperture can be anticipated, even with β-beat in excess of 20 %.

An illustration of where the new booster will be located in relation to the existing booster and transfer lines is shown in Fig. 6. The transfer lines from the linac and to the storage ring will need to be reconfigured for the new ring, with injection components in one long straight and extraction elements in the other. An injection scheme that allows off-axis injection and accumulation using three kickers and a standard septum magnet is under development. The same magnets could be configured for on-axis injection during commissioning, or if accumulation is not required. It is assumed that extraction will use a single fast kicker with 200 ns rise time plus an extraction septum, allowing a continuous train of up to 184 bunches to be stored in the ring. The two 5-cell normal conducting cavities will be relocated from the existing booster. The new booster will be partially constructed around the outside of the existing ring during the standard shutdowns preceding the main shutdown, with final installation and commissioning taking place whilst the existing storage ring is being removed.

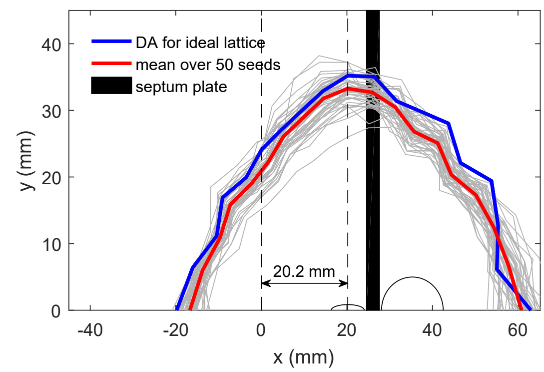

Figure 5: Dynamic aperture including field and alignment errors for the proposed booster design. The effect of the injection bump, damped beam and injected beams are shown.

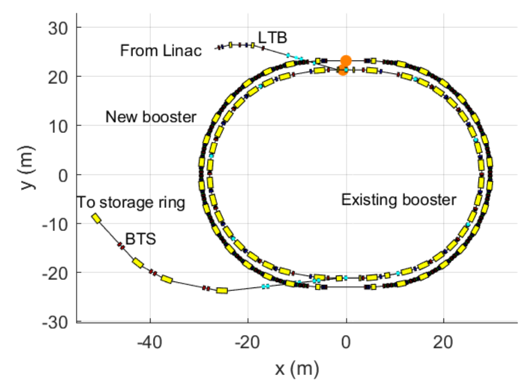

Figure 6: Location of the new booster super-imposed on the existing injector complex.

CONCLUSIONS

A viable, off-axis injection scheme that provides close to 100 % injection efficiency has been developed for the Diamond-II storage ring. Despite this, several potential areas of improvement remain under investigation, such as how to minimise the expected injection transients and which type of pulsed magnets to use. A conceptual design of the new booster required for the upgrade has also been presented, however, significant work remains to be carried out on both aspects to convert the proposals into fully engineered solutions.

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