ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF008

CONCEPTUAL DESIGN OF AN ACCUMULATOR RING FOR THE DIAMOND II UPGRADE

I.P.S. Martin, R. Bartolini[1], Diamond Light Source, Oxfordshire, U.K.
[1]also at John Adams Institute, University of Oxford, U.K.

Abstract

Diamond Light Source is in the process of reviewing several lattice options for a potential storage ring upgrade. As part of these studies, it has become clear that a substantial reduction in emittance can be achieved by adopting an on-axis injection scheme, thereby relaxing the constraints on the dynamic aperture. In order to achieve the necessary injected bunch properties for this to be viable, a new accumulator ring would be needed. In this paper we review the requirements placed on the accumulator ring design, describe the lattice development process and analyse the performance of the initial, conceptual design.

INTRODUCTION

In order to meet the future needs of its users, Diamond Light Source is currently studying different lattice options for a potential storage ring upgrade [1]. This process has shown a clear correlation between a reduction in the emittance and the resulting dynamic aperture for any given lattice design. As such, if the lowest possible emittance is taken as the primary design goal, a switch from off-axis to on-axis injection may be required.

Several on-axis injection schemes have been proposed in recent years, with swap-out injection [2, 3] and longitudinal injection receiving most attention [4]. In each case, the electron bunches extracted from the injector complex must meet certain requirements, with high bunch-charge a pre-requisite for swap-out. Similarly, a low emittance and short bunch length are both highly desirable to maximise capture efficiency. For longitudinal injection, it may also be necessary to switch from a 500 MHz to a 100 MHz RF system to enable sufficient time for the injection kicker to reach field between the individual bunches.

The existing Diamond injector is not capable of generating the high bunch charges required for swap-out injection. As such, an additional accumulator ring would be needed between the existing booster synchrotron and any new storage ring. Two options are under consideration for this. The first is to convert the existing storage ring into an accumulator ring in the same tunnel, the second is to build a new ring inside the booster tunnel. Placing the accumulator ring inside the storage ring tunnel would generate a smaller emittance and allow existing hardware to be re-used. However, the logistical drawbacks of reduced space and longer installation and commissioning time make the booster tunnel option more attractive. In this paper, we review the requirements placed on the accumulator ring design, describe the lattice development process for the booster tunnel option and analyse the performance of the initial, conceptual design.

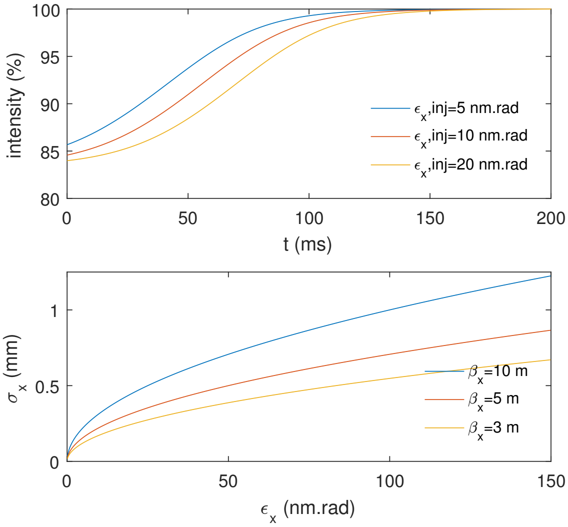

Figure 1: Top: loss of intensity during swap out assuming 1/6 of the beam is replaced. Bottom: injected beam size as a function of emittance neglecting dispersive contributions.

ACCUMULATOR RING DESIGN

Requirements

The main consideration for any new accumulator ring is what value of emittance should be targeted. This parameter impacts performance in a number of ways. For swap-out injection into the Diamond II storage ring, it is envisaged that up to 1/6 of the bunches in the storage ring will be replaced in a single shot, leading to a transient drop in brightness as the injected bunches damp to the stored beam emittance. This effect is illustrated in the top plot of Fig. 1, where a stored beam emittance of 100 pm.rad, 20 ms damping time and a 4σ aperture restriction in the beamline have been assumed. In order to make the swap-out completely transparent to users, the injected beam emittance would need to match that of the stored beam. For the likely range of emittances studied here, the impact appears relatively weak.

Also shown in Fig. 1 is the transverse beam size as a function of emittance for several values of β_x. Smaller beam sizes can benefit on-axis injection by reducing the dynamic aperture requirements of the storage ring and by minimising the sensitivity to beam jitter. If the emittance of the injected beam could be reduced from the existing booster emittance of 140 nm.rad by a factor ~10, there would be a reduction in the injected beam σ_x from ~0.7 mm to ~0.2-0.3 mm. This is then comparable in magnitude to the shot-to-shot jitter and slow drift in position experienced at Diamond over the course of a typical run.

The main requirements identified for the accumulator ring design are therefore:

- low emittance (1-20 nm.rad)
- short bunch length
- sufficient dynamic aperture for off-axis accumulation
- high injection efficiency to minimise fill-time
- low impedance to accommodate high bunch charges
- long lifetime compared with swap-out period
- fit within existing tunnel / accelerator constraints
- space for ancillary equipment (RF, pulsed magnets, diagnostic equipment, etc.)

Unit Cell Design

The accumulator ring design began as a simple unit cell consisting of one dipole, two families of quadupoles and two families of sextupoles, as shown in Fig. 2. This structure was then replicated N_{cells} times with a fixed average bend radius of 23 m, consistent with installation in the existing booster tunnel. The behaviour of each design was determined by systematically scanning the quadrupole strengths in a grid, then for each set-point calculating the main parameters such as emittance, energy loss per turn, momentum compaction factor, natural chromaticity, damping times and dynamic aperture at zero chromaticity. An example of one such scan for the vertical dynamic aperture is shown in Fig. 3.

From this study, a ring consisting of 32 cells was found to best meet the overall requirements, offering an emittance of ~10 nm.rad, large dynamic aperture and moderate beta functions, whilst keeping the energy spread, energy loss per turn and overall number of magnets low.

Following this, the unit cell design was refined by scanning the lengths of each magnet and again determining the impact on the main lattice parameters, with the minimum magnet spacing set to 10 cm. The integer horizontal cell tune was selected in order to minimise the emittance, and the integer vertical cell tune was chosen to minimise the natural vertical chromaticity.

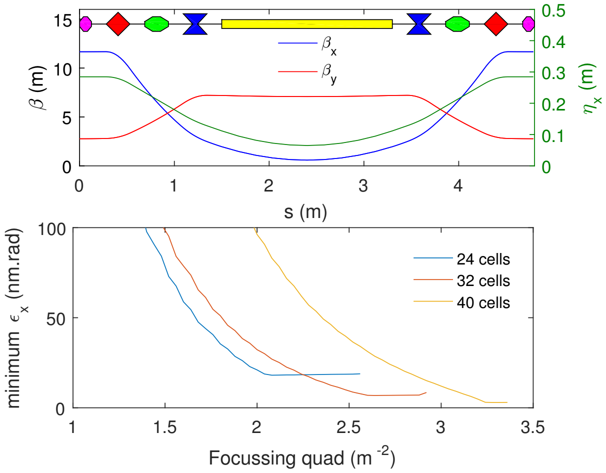

Figure 2: Top: basic structure of a unit cell. Bottom: emittance scaling with number of cells (fixed magnet lengths).

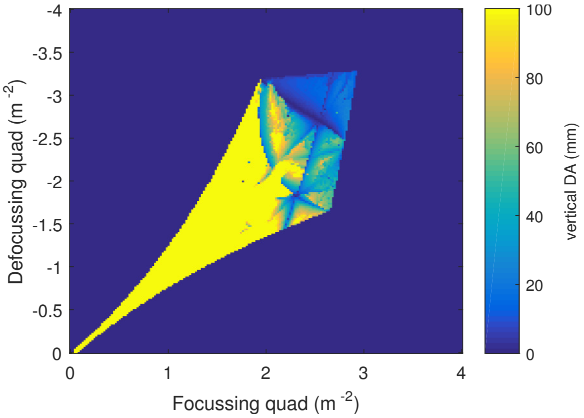

Figure 3: Vertical dynamic aperture vs. quadrupole strength after chromaticity correction for a 32-unit cell lattice.

Matching Cell Design

The next stage of the design was to convert the circular ring into a practical design with dispersion-free straight sections suitable for injection and extraction. This was achieved by splitting the ring into two arcs to form a racetrack structure, similar to the existing booster. A short matching section was then added, with a half-length dipole added after a 1.5 m long drift section to act as a dispersion suppressor (see Fig. 4). Once the basic structure of the ring was established, the phase advances across the long straights were adjusted in order to adjust the final working point of the lattice, whilst keeping appropriate amplitude of beta functions.

Each super-period therefore consists of 14 unit cells plus two matching cells, giving two long straight sections of 9 m in length. These straights will house the injection elements for the booster to accumulator ring transfer line, the extraction elements for the accumulator to storage ring transfer line and potentially the additional elements required to allow the depleted bunches to be re-captured once extracted from the storage ring. The short straight sections in the matching cells are envisaged to be used for accommodating RF cavities or diagnostics equipment.

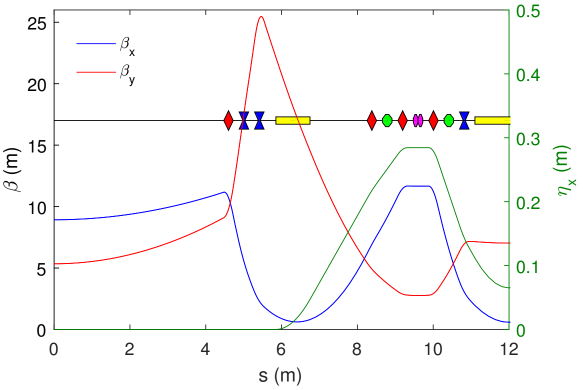

Figure 4: Twiss parameters for one half of the long straight sections plus the matching cell.

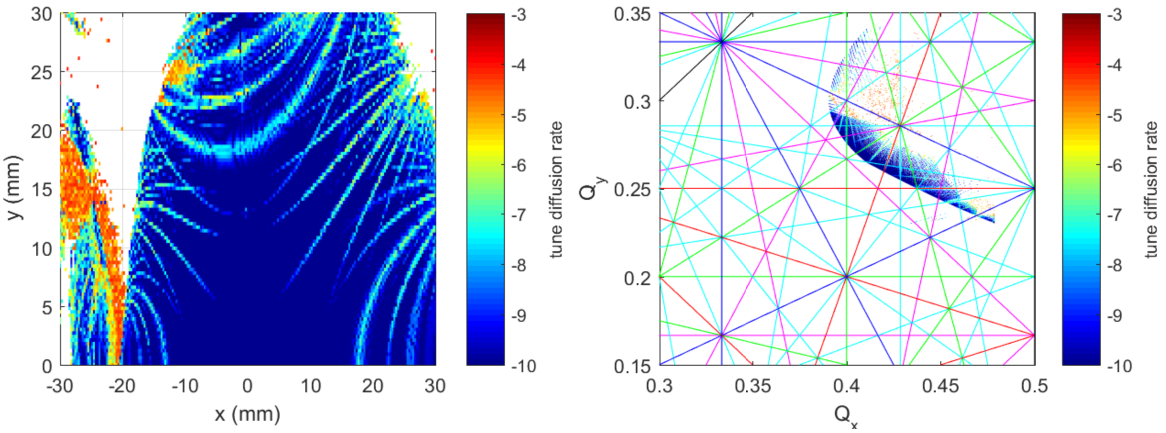

Figure 5: Left: on-momentum dynamic aperture for the accumulator ring. Right: corresponding frequency map.

Ring Parameters

A plot of the Twiss parameters for one super-period of the accumulator ring design is shown in Fig. 6, and a comparison of the main parameters of the lattice with the existing booster synchrotron are given in Tab. 1. From this it is clear the main requirements of the design have been met, with over an order of magnitude reduction in emittance having been achieved. The on-momentum dynamic aperture of the lattice is shown in Fig. 5, showing that even at this early stage sufficient aperture for off-axis injection is available.

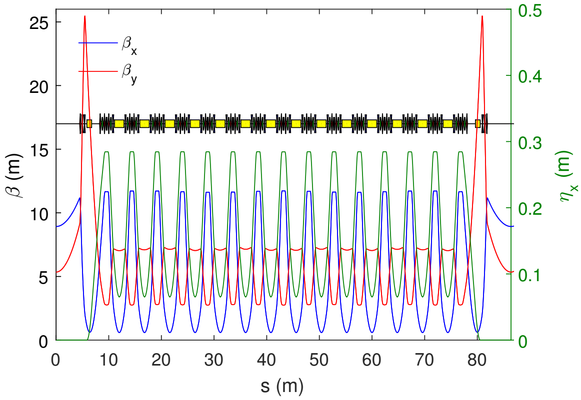

Figure 6: Twiss parameters for one super-period.

DISCUSSION

Before the design of the accumulator can be completed, further work on the storage ring needs to be carried out. In particular, knowledge of the available dynamic aperture will allow the decision on whether to adopt on or off-axis injection to be made, and the shape of the RF bucket will influence the choice of bunch length for the injected beam.

At present, the design of the accumulator ring has been based on the assumption that swap-out injection will be required. However, even if off-axis accumulation is adopted, the installation of an accumulator ring has certain benefits.

Table 1: Main Lattice Parameters

Parameter	**Booster**	**Accumulator**
Circumference	158.4 m	172.8 m
Betatron tunes	[7.18,4.27]	[13.41, 5.26]
Natural chromaticity	[-9.7,-6.3]	[-27.9, -10.2]
Emittance	134.4 nm.rad	9.7 nm.rad
Energy spread	7.3×10^{-4}	8.8×10^{-4}
Energy loss per turn	579 keV	834 keV
Mom. compact. factor	2.5×10^{-2}	2.8×10^{-3}
Bunch length (2 MV)	59.6 ps	25.4 ps
Damping times (τ_x, τ_s)	5.5, 2.7 ms	4.1, 2.1 ms

For example, the reduced emittance and bunch length from the accumulator means it would be possible to move the injected beam closer to the septum plate and hence relax the on and off-momentum dynamic aperture requirements for the storage ring. Any accumulation could also be carried out in the accumulator ring rather than the storage ring, such that injection into the storage ring would be single shot. This would minimise the disturbance to the stored beam experienced by users. The smaller horizontal beam size would also make it more suitable for injection using a non-linear kicker, as it would be easier to shape the kicker profile to allow all electrons in the injected bunch to experience the same kick-angle [5].

The next steps in the development of the accumulator ring are to optimise the layout for a more practical, engineering-compliant design. During this process, the magnet lengths and strengths will be varied in order to achieve the best beam dynamics and magnet apertures consistent with the main goals established for the lattice. This will include extensive error analysis, including developing effective orbit and optics correction schemes to ensure a robust design. In parallel, injection and extraction lines need to be developed, potentially including a new storage ring to accumulator transfer line for the depleted bunches. Finally, an assessment of collective effects for high-charge bunches needs to be made.

REFERENCES

[1] B. Singh *et al.*, “Lattice Options for Diamond II”, in *Proc. IPAC’18*, Vancouver, Canada, May 2018, paper THPMF009, this conference.

[2] M. Borland, “On-axis Swap-out Injection”, in *Proc. Workshop on Accelerator R&D for Ultimate Storage Rings*, Beijing, China, 2012.

[3] C. Steier *et al.*, “Progress of the R&D Towards a Diffration Limited Upgrade of the Advanced Light Source”, in *Proc. IPAC’15*, Richmond, VA, USA, May 2015, paper TUPMA001, pp. 1840–1842.

[4] M. Aiba *et al.*, “Longitudinal Injection Scheme using Short Pulse Kicker for Small Aperture Electron Storage Rings”, *Phys. Rev. ST Accel. Beams*, vol. 18, 020701, 2015.

[5] S.C. Leemann, L.O. Dallin, “Progress on Pulsed Multipole Injection for the MAX IV Storage Rings”, in *Proc. NA-PAC’13*, Pasadena, CA, USA, Oct 2013, paper WEPSM05, pp. 1052–1054.