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APERTURE SHARING INJECTION FOR DIAMOND-II

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Abstract

The planned Diamond-II storage ring will provide users with an increase in brightness of up to two orders of magnitude compared with the existing Diamond facility. The aim is to maintain excellent photon beam stability in top-up mode, which requires frequent injections. This paper introduces the aperture sharing injection scheme designed for Diamond-II. The scheme promises, through the use of short striplines equipped with high-voltage nano-second pulsers, a quasi-transparent injection while maintaining an approximately 100% injection efficiency.

INTRODUCTION

Traditionally, the injection process in storage ring-based synchrotron light sources has been driven by the use of transverse closed-orbit bumps created by pulsed dipole kickers in order to achieve off-axis accumulation. The inevitable non-closure of the orbit bumps, due to kicker imperfections or mis-match, leads to leakage of betatron oscillations to the remaining sections of the storage ring. These residual oscillations can create non-negligible photon beam perturbations for some beamlines, who may have to gate their detectors during the injection process, or attempt to schedule their measurements in the quiet-time between top-up cycles. Another option is to try to counteract the oscillations by means of a compensation kicker [1, 2]. With the new generation of synchrotron light sources based on multi-bend achromat (MBA) lattices, alternative injection schemes seek to conform with the relatively restricted dynamic- and momentum aperture while staying transparent (i.e., perturbation-free) to the users.

Diamond-II is the upgrade of the United Kingdoms national light source [3, 4]. The new storage ring will be based on the Modified Hybrid Six-bend Achromat (M-H6BA), which includes ≈2.9 m straight section in the middle of the achromat ("mid-straights"), which can accommodate short insertion devices, cavities, injection elements etc.

The performance of several different injection schemes has been evaluated for top-up into Diamond-II. It was found that a single-bunch aperture sharing scheme provides the best compromise between reliability and transparency to the users, and will therefore be used during user operation. A combined thick- and thin septum situated in a single vacuum tank in the injection straight, inspired by developments for SLS 2.0 [5], is planned. A traditional four-kicker bump in the injection straight will be maintained for easy commissioning, fast multi-bunch filling and as a safe fall-back option. Furthermore, a static chicane is introduced in the injection straight to maximize flexibility [4].

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The remainder of this paper will describe the aperture sharing scheme, its expected performance and some key beam dynamics challenges.

SINGLE-BUNCH APERTURE SHARING

Top-up injections by single-bunch aperture sharing, to our knowledge initially proposed for the SLS 2.0 upgrade [6], is a bump-free injection scheme which uses short-pulse striplines to kick the injected beam towards the storage ring axis while simultaneously kicking the stored beam away from the axis. If the dynamic aperture is great enough, it is possible to kick the injected beam into the storage ring acceptance without kicking the stored beam out. The kicked bunches will then exhibit betatron oscillations around the closed orbit and are damped over time by synchrotron radiation emission.

The striplines must be fit into available space in the storage ring, and preferably at a phase advance equal to an odd multiple of $\pi/2$ after the exit of the septum magnet for the best possible compensation. The mid-straights in the H-M6BA lattice design can accommodate several striplines and has a reasonable phase advance when the effect of the nonlinear magnets in the first half achromat is included. It was found that four striplines with 150 mm effective length will provide the best form factor while maintaining reasonable pulser requirements.

The position, angle and twiss parameters of the injected beam at the exit of the thin septum, together with the kick angle of the stripline kickers is optimized by numerically minimizing the horizontal RMS Courant-Snyder invariant of both the injected- and stored beam after the last stripline:

$$I_x = \frac{x^2 + (\alpha_x x + \beta_x x')^2}{\beta_x}, \tag{1}$$

where β_x and α_x are the twiss parameters after the last stripline. The optimum kick angle for each stripline is $\theta = -176$ µrad.

A sketch of the aperture sharing implementation is shown in Fig. 1 together with the trajectory of the injected- and stored bunch centroids. The horizontal phase space of the two bunches during the first 50 turns is plotted in Fig. 2. Slightly more than 4 mm of DA is required, which is well-within what the storage ring is expected to deliver.

Robustness against Injection Mis-steering

A beam coming from the booster with the nominal parameters into an ideal storage ring is injected with 100% efficiency. Such a situation is too idealistic to evaluate the robustness of the injection scheme. Lattice and physical errors in storage ring will be present, and positional and angular errors due to mis-steering of the injected beam in the booster-to-storage ring transfer line, or jitter from the pulsed magnets involved

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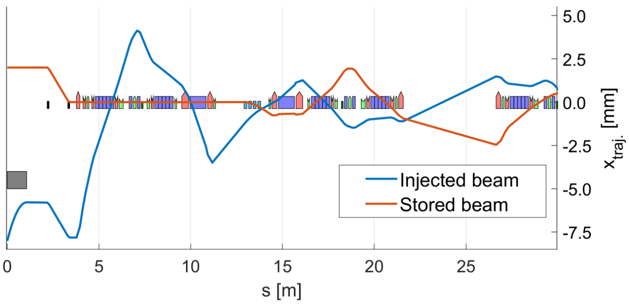

Figure 1: Trajectory of injected- and stored bunch centroids through the first achromat during single-bunch aperture sharing. Chicanes are set to a 2 mm static bump.

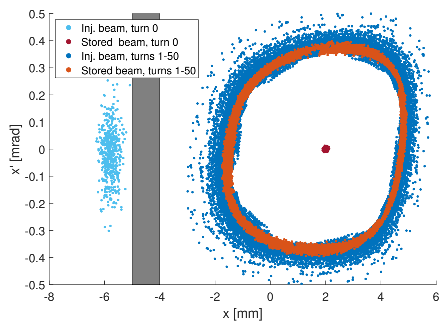

Figure 2: Horizontal phase space of injected- and stored bunch over the first 50 turns after single-bunch aperture sharing injection. The gray square indicates the septum blade. Chicanes are set to a 2 mm static bump.

in the injection process, might deteriorate the injection efficiency. The robustness of the injection is evaluated by calculating the injection efficiency for various mis-steerings and mis-match of the injected beam at the exit of the septum. We perform the simulations for 20 lattice seeds which have undergone the Simulated Commissioning [7] procedure including insertion devices, collimators and apertures. The SC procedure for Diamond-II is described in [8]. Contour curves indicating the average expected injection efficiency are shown in Fig. 3. The coordinates indicate the injected bunch centroid offsets with respect to the storage ring closed orbit at the exit of the thin septum magnet. The results indicate that the centroid can be mis-steered by 0.75 mm horizontally (Fig. 3a) and 0.5 mm vertically (Fig. 3b) while maintaining >95% injection efficiency. Mis-match of the optics (Fig. 3c) do not have a great impact (effect of vertical mis-match is not shown here due to their lack of impact). Interestingly, it is found to be beneficial to have ≈ +0.5% energy offset (Fig. 3d). These simulations provide confidence that aperture sharing will be a good injection scheme for Diamond-II.

Impact of Short-range Wakefields

Transversely oscillating charges may induce short-range wake-fields that leads to beam blow-up and in the most severe cases also beam loss [9, 10]. Both stored- and in-

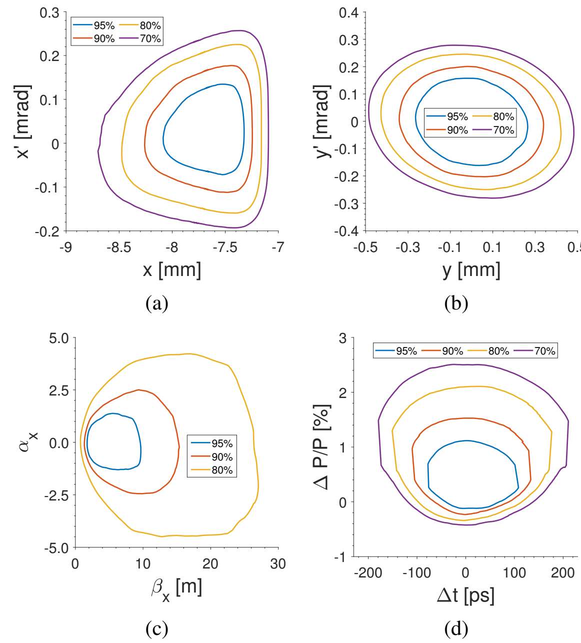

Figure 3: Contour indicating the expected efficiency of single-bunch aperture sharing injection into the Diamond-II storage ring for various mis-steerings and mis-match at the exit of the thin septum magnet.

jected beam will oscillate with a few millimetres of amplitude. Therefore, the injection is simulated using element-by-element tracking including the short-range storage ring impedance in `elegant` [11]. Both transverse- and longitudinal impedances are included and distributed to 24 different locations around the ring. The simulation is done for five seeds of lattice errors which reproduces the expected lattice errors after commissioning. The charge of the injected bunch is set to 0.1 nC, while the stored bunch range from the nominal filling pattern charge of 0.62 nC to higher charges of 2-4 nC to study the injection into a camshaft bunch in a hybrid filling pattern. The net charge gain after injection is shown in Fig. 4; a step of 0.1 nC indicates a 100% injection efficiency. No losses are seen up to a stored bunch charge of 3 nC, while some seeds indicate substantial losses at 4 nC. Several mitigation techniques can be considered: First and foremost, the kick from the striplines can be lowered to decrease the oscillation amplitude of the high-charge stored bunch, with the drawback being that a larger DA is required. Secondly, studies performed at ALS [12] suggests that a higher chromaticity reduces losses. Simulations for Diamond-II indicate that higher vertical chromaticity is helpful. Thirdly, in [12] it was also found beneficial to have a time separation between the stored and injected bunch. Preliminary simulations suggest that ≈75 ps separation reduce losses. Lastly, it has been shown that a larger nonlinear tune shift with amplitude generated by octupoles helped stabilise the beam at injection in the APS-U lattice [13]. This method is yet to be tested on the Diamond-II lattice.

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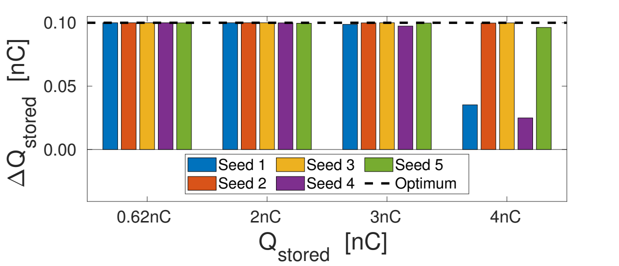

Figure 4: Net charge gain during aperture sharing injection including collective effects.

Stripline Requirements

The required stripline voltage is estimated using the simplistic formula [14]

$$U = \frac{\theta E h}{4L}, \tag{2}$$

where U is the voltage applied to each stripline (with opposite sign), L is the effective length of the stripline, E is the beam energy in eV and h is the gap between the striplines. The proposed stripline design has $h = 14\,\mathrm{mm}$ and $L = 150\,\mathrm{mm}$, indicating that $\pm 14\,\mathrm{kV}$ is required.

The aim of the injection scheme is to have as little perturbation to the stored beam as possible. Ultimately, the goal is to perturb only a single stored bunch. For a 150 mm stripline, the maximum pulse duration to avoid adjacent bunches being perturbed is given by the equation:

$$\tau_\mathrm{p} = \tau_\mathrm{r} + \tau_\mathrm{FT} + \tau_\mathrm{f} \leq \frac{2}{f_\mathrm{RF}} - \frac{2L}{c} = 3\,\mathrm{ns}, \tag{3}$$

where τ_FT is the flat-top duration and τ_r and τ_f are the rise- and fall-times, respectively, f_RF is the storage ring RF frequency and c is the speed of light. To exploit the full length of the striplines the pulse flat-top must be

$$\tau_\mathrm{FT} \geq \frac{2L}{c} = 1\,\mathrm{ns}. \tag{4}$$

The stripline design is currently under development and is inspired by similar structures required for SLS 2.0 [15].

ENHANCED APERTURE SHARING

An alternative set of optics for Diamond-II which pushes the brightness further at the expense of smaller DA and lower lifetime is being investigated [16]. The DA is too small to accommodate aperture sharing, and therefore on-axis injection schemes such as longitudinal injection [17] and swap-out [18] were considered. The Diamond-II optics cannot provide enough momentum acceptance for longitudinal injection, while swap-out requires full-charge bunches from the booster together with substantially stronger stripline kickers. A new injection scheme was therefore devised which allows for off-axis accumulation into a smaller dynamic aperture. The concept is, in principle, a single-bunch two-kicker bump which is unclosed. An additional five striplines are

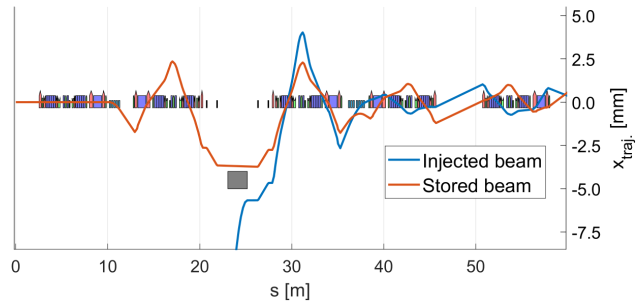

Figure 5: Trajectory of injected- and stored bunch centroids through the first achromat during enhanced aperture sharing. Chicanes are set to a −1 mm static bump.

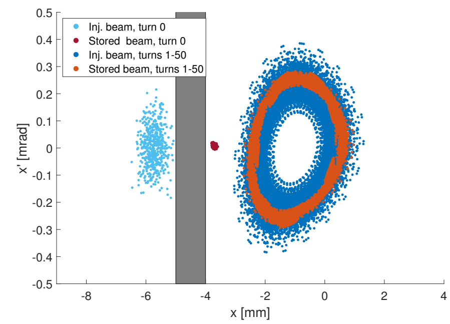

Figure 6: Horizontal phase space of injected- and stored bunch over the first 50 turns after enhanced aperture sharing. Chicanes are set to a −1 mm static bump.

added to the mid-straight upstream of the injection straight, together with three more in the first down-stream injection straight. The trajectory of the stored- and injected bunch is shown in Fig. 5. The corresponding horizontal phase space after the first 50 turns is presented in Fig. 6. Only around 2 mm of DA at the exit of the thin septum is required for successful accumulation. A DA of ≈4 mm is within reach [16]. For this scheme the stripline voltages remain below 20 kV.

CONCLUSION

A single-bunch aperture sharing scheme utilizing four short-pulse, high-voltage striplines will be used for top-up injection into the planned Diamond-II upgrade. The stripline kickers will be located in the mid-straight of the first achromat, and will kick the injected bunch into the storage ring acceptance while kicking the stored bunch slightly off-axis. The scheme requires around 4 mm horizontal dynamic aperture which is within what the new storage ring will deliver. The robustness of the injection has been confirmed by simulating mis-steering of the injected beam as it exits the septa. The influence of short-range wakefields have been simulated, and found to be potentially harmful for the camshaft bunch in hybrid mode operation. Mitigation techniques are found to be helpful. A new "enhanced" single-bunch aperture sharing scheme is proposed for injecting into the alternative high-brightness Diamond-II optics, and allow for off-axis accumulation into a ≈2 mm dynamic aperture.

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