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A KICK-AND-CANCEL INJECTION SCHEME FOR DIAMOND-II

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Abstract

The Diamond-II storage ring upgrade will provide users with 1-2 orders of magnitude brightness increase over the existing Diamond facility, for which a quasi-transparent top-up injection scheme will be a key performance requirement. The ring was originally designed to use a single-bunch aperture sharing injection scheme, in which short stripline kickers are used to kick the injected bunch into the storage ring's dynamic aperture but remaining weak enough to avoid kicking the stored bunch outside the acceptance. A modification to this scheme which implements a kick-and-cancel method shows promise for the stored bunch. The kicker power supplies are thus required to provide a double-pulse with few-microsecond pulse spacing. This new method is expected to significantly improve the transparency and reduce the recovery time for the targeted bunch, along with minimizing transverse wakefield effects and any interactions with the transverse multibunch feedback.

INTRODUCTION

The Diamond-II storage ring has been developed to provide users with an increase in brightness over the existing Diamond facility, for which a quasi-transparent top-up injection scheme will be a key performance requirement [1]. The transparency goal is that the Figure of Merit (FoM), defined as the light flux integrated over 100 µs through transverse full-width half-maximum slits located 45 meters downstream of the source center, is kept above 99 % of the nominal value (threshold) for all beamlines during injection.

Originally, top-up injection for Diamond-II was to use the Aperture Sharing (AS) method and has been demonstrated to perform with quasi-transparency in brightness [2,3]. This scheme uses short stripline kickers to kick the injected bunch into the storage ring's dynamic aperture, while the top-up stored bunch is perturbed but remains within the dynamic aperture.

To improve the transparency–reducing brightness recovery time, a Kick-and-Cancel (KC) [4] injection scheme is now under study. In this scheme, two kicks are applied to the stored bunch, separated by a few microseconds, with the aim of enabling injection with only transitory stored bunch oscillation. The first pulse kicks the stored bunch to introduce a perturbation. The stored bunch then propagates in non-closed orbits for a few turns (defined as preparation turns) until the phase advance becomes 180 degrees at the kickers. The pulse spacing is adjusted so that the second kick cancels the perturbation and is timed to coincide with the arrival of the injected bunch.

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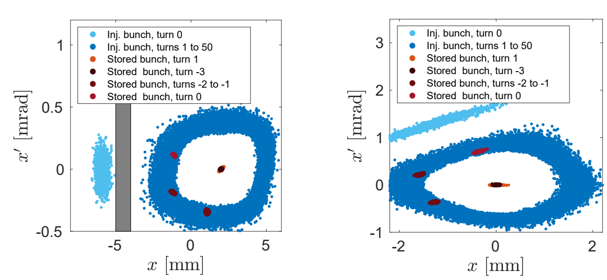
To investigate the KC scheme, Accelerator Toolbox (AT2) [5, 6] simulations are carried out with an optimizer developed to maximize the perturbation cancellation. With the optimizer, the horizontal betatron tune and stripline kick angles are adjusted to minimize the residual stored bunch oscillations.

Since the top-up stored bunch's perturbation is canceled by the KC scheme, the brightness contributed by the stored bunch is quickly recovered. Therefore, the scheme could allow acceptable quasi-transparency during the top-up injection of a hybrid bunch. The transparencies in brightness for both standard operation with 899 bunches in the storage ring and hybrid bunch operation are explored via AT2 simulations. Finally, the impact of transverse wakefield effects is studied using ELEGANT [7, 8], as the KC scheme with the perturbation cancellation is expected to improve the injection efficiency drastically.

KICK-AND-CANCEL SCHEME FOR DIAMOND-II

In the KC scheme for Diamond-II, the four stripline kickers are located in the K01 mid straight ~ 13 m downstream from the septum in the I01 injection straight. These are used to kick the top-up stored bunch twice to introduce and cancel the perturbation, while only in the second time they also kick the injected bunch into the storage ring's dynamic aperture.



(a) (b)

Figure 1: Horizontal phase space distribution of injected and stored bunch in Kick-and-cancel scheme for Diamond-II at (a) the exit of the septum in the injection straight I01 and (b) the entrance of the first stripline kicker in the middle straight K01.

As the Diamond-II storage ring is currently designed with a residual horizontal tune Q_x of 0.14, after the first kick with kick angles (from each kicker) of 163.15 µrad, the stored bunch propagates 3 turns (3 preparation turns, corresponding to 5.61-µs pulse spacing), and the phase advance becomes

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~ 180 degrees at the kickers. Then the second kick is applied to both the injected and stored bunch with kick angles (from each kicker) of 175 µrad, which is the nominal value in the AS scheme for Diamond-II [3]. Due to lattice nonlinearities, the maximum cancellation occurs if the two kick angles are set for different values. Figure 1 shows the horizontal phase space distribution of both injected and stored bunch, while Fig. 2 shows trajectories of injected and stored bunch in the KC scheme for Diamond-II from the septum to the middle of the SM girder in cell 2. In Fig. 1, the stored bunch is finally kicked back into the original trajectory with the same $x-$ and $x'-$centroids. However, the emittance of the stored bunch is increased due to non-linear distortions in the phase space during the process.

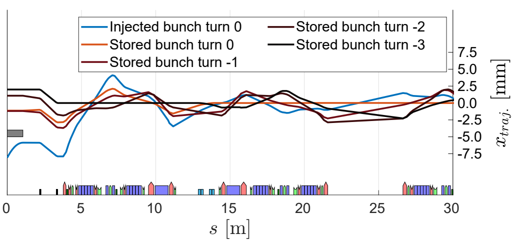

Figure 2: Trajectories of injected and stored bunch in Kick-and-cancel scheme for Diamond-II from the septum to the middle of the Standard-to-Mid (SM) girder in cell 2, where the stripline kickers are located at $s =\sim 13$ m.

Simulation Setup and Parameter Optimizer

A Matlab simplex optimizer has been developed to minimize the residual stored bunch oscillation by adjusting the storage ring horizontal tune and the first kick angle within their feasible ranges. Thus, the goal function of the optimizer becomes to minimize the Courant-Snyder (CS) invariant of a single stored particle in the x-axis after the second kick, written as

$$I_x = \frac{(x^2 + \alpha_{x,\mathrm{SR}} x + \beta_{x,\mathrm{SR}} x')^2}{\beta_{x,\mathrm{SR}}}, \quad (1)$$

where $\beta_{x,\mathrm{SR}}$ and $\alpha_{x,\mathrm{SR}}$ are the storage ring optical functions downstream of the final stripline kicker. (x, x') is the phase space coordinate of the single stored particle downstream of the final stripline kicker, obtained by the AT2 particle tracking.

Horizontal Tune and Stripline Kick Angle

The number of preparation turns dictates precisely both horizontal tune and stripline kick angle to maximize the perturbation cancellation. Figure 3 shows plots of optimized residual horizontal tune and first kick angle as a function of number of preparation turns, where the second kick's stripline kick angle remains 175 µrad. In other words, in the KC scheme, the storage ring must be operated with the precise horizontal tune, and corresponding stripline kick angle and number of preparation turns for the maximum perturbation cancellation.

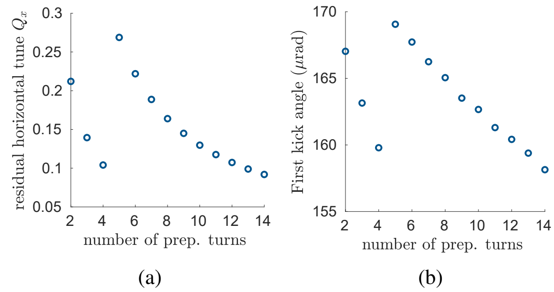

Figure 3: Plots of (a) optimized residual horizontal tune and (b) optimized first kick's stripline kick angle as a function of number of preparation turns.

Power Supply Prototype

A power supply (pulser) with adjustable few-microsecond pulse spacing is a key component of the stripline. As of mid-2024, Kentech Instruments Ltd. has been developing the pulsers for Diamond-II to perform the KC scheme. The first prototype demonstrated the ability to produce multiple pulses with programmable amplitude for each pulse. The burst pulse spacing can be as short as ~ 1 µs. This prototype produces relatively long pulses of 15 ns overall duration. The second-stage prototype has demonstrated a 4-ns pulse width and amplitude of > 4 kV with the same burst performance. However, the ideal pulse (total pulse length < 3 ns with ~ 1.2-ns flattop) is anticipated that this will predominantly kick only the target stored bunch. The next prototype pulser currently under development aims to increase the voltage to > 15 kV and improve the pulse shape, in particular the post-pulse noise. In the brightness study for the KC scheme, both ideal and longer pulses have been studied.

BRIGHTNESS STUDY

In the brightness study, the evolution of the brightness–drop and recovery–is observed and the brightness recovery time is estimated, where the FoM represents the brightness and is computed using the results of AT2 particle tracking. Each perturbed stored bunch contributes the brightness drop (to the lowest bunch FoM), before the brightness is recovered during the radiation damping process [3].

Pulse Timing and Standard Operation

The prototype can perform the double pulse but with each single pulse total length longer than the ideal pulse as Diamond-II bunch spacing is only 2 ns. As a result, the stored bunches kicked by the rise and fall time signal propagate with different amplitudes of oscillation than the ones kicked by the flattop signal. Tune-shift with amplitude means that, while the stored bunches kicked by the flattop signal acquire the optimized perturbation cancellation, the ones kicked by the rise and fall time signal do not. A pulse timing optimizer has been developed to minimize the overall brightness drop or maximize the lowest beam FoM. In this study, the long pulse profile has been defined as a 5-ns flattop with

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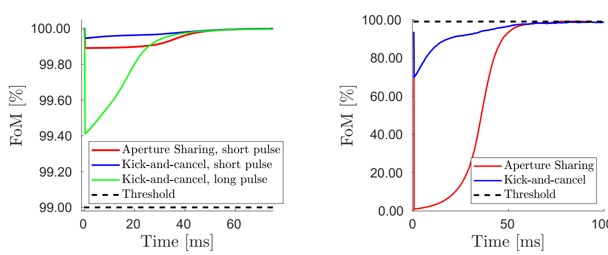
linear rise and fall time of 5 and 6 ns, respectively. Such a long pulse perturbs the adjacent stored bunches (7 additional bunches in total) and reduces the brightness further. Essentially, the FoM simulation is used to determine the pulse timing that provides the minimum overall brightness drop during the standard operation top-up.

In this study, a 0.2-nC injected bunch tops up the 0.4-nC stored bunch, so the total bunch charge becomes 0.6 nC again. Figure 4a shows the evolution of the full beam brightness for both the KC and AS schemes, where the bunch charge of other stored bunches than the top-up is assumed to remain 0.6 nC. Note that the short pulse is modeled as the ideal pulse, thereby not perturbing any other stored bunches than the target. The KC scheme's recovery time surpasses the AS scheme's and can be improved further with the ideal pulse.

Hybrid Bunch Mode

The hybrid bunch has a total charge of 3 nC, as a 0.2-nC injected bunch tops up a 2.8-nC stored bunch. With the KC scheme in the hybrid bunch mode, the FoM only drops to 70 %, as shown in Fig. 4b. Moreover, the KC scheme's recovery time is lower than the AS scheme's as well.



(a) (b)

Figure 4: Evolution of FoM during the KC and AS scheme in (a) the standard operation and (b) the hybrid bunch mode.

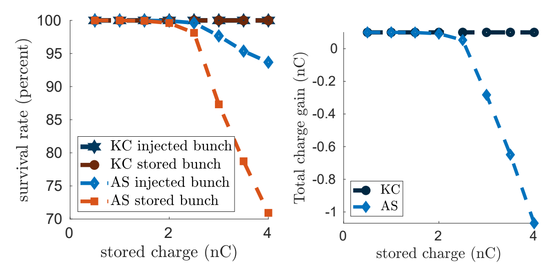
SHORT-RANGE WAKEFIELDS

Collective effects during the KC and AS injection schemes have been investigated using ELEGANT, tracking both injected and stored bunches. In this study, the injected bunch charge is fixed to 0.1 nC with a macroparticle charge of 0.1 pC. Consequently, a 4-nC stored bunch, for example, is represented by 40,000 macroparticles.

Injection efficiency has been calculated as a function of stored bunch charge including short-range wakes and an ideal harmonic cavity (set to flat potential conditions). The simulation setup includes impedance elements (resistive wall, cavity HOMs, and geometric) [9], field errors (20 seeds), physical apertures including insertion device (ID) gaps, and closed collimators.

In the simulation, a stored bunch is firstly generated and tracked for 12,000 turns including the impedance and the harmonic cavity to reach equilibrium. Then an injected bunch is generated and added to the simulation after the septum, and the striplines are fired as appropriate for either AS or KC schemes. Finally, both injected and stored bunches are tracked for a further 3,000-6,000 turns to determine the injection efficiency and the total bunch charge gain.

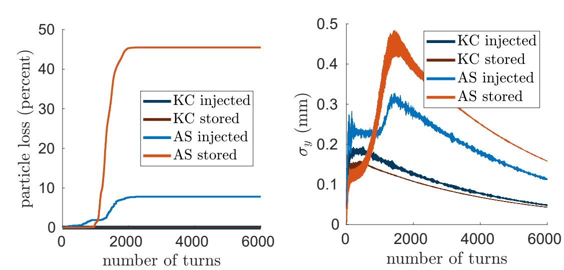
Figure 5 shows the average survival rate of the injected and stored bunches and the average total charge gain during injection as a function of stored bunch charge for both schemes. Note that these results are averaged over 20 error seeds. The results show that the particles are lost drastically for stored charges higher than 2.5 nC in the AS scheme only, as the negative total charge gain indicates that the total charge is below the original charge prior to the top-up injection.



(a) (b)

Figure 5: Survival rate (a) of injected and stored bunches and total charge gain (b) during KC and AS schemes as a function of stored bunch charge.

Figure 6 shows the evolution of particle loss and y-rms beam size σ_y throughout the injection tracking with 4-nC stored bunch (single error seed). Only in the AS scheme, the y-beam size blow-up to ~ 0.5 mm causes significant stored bunch loss at the y-collimators, since the y-dynamic aperture for Diamond-II is only ~ 1 mm with collimators closed.



(a) (b)

Figure 6: Evolution of (a) particle loss and (b) y-rms beam size during KC and AS schemes with 4-nC stored bunch.

CONCLUSION

The KC scheme shows promise in improving the top-up injection at Diamond-II with significantly lower brightness recovery time and the possibility of topping up a hybrid bunch with acceptable transparency. Ultimately, in the collective effect study, the KC scheme drastically improves the injection efficiency over the AS scheme allowing higher stored bunch charges to be reached.

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REFERENCES

[1] R.P. Walker *et al.*, "Diamond-II Technical Design Report, Aug 2022", Diamond Light Source, Didcot, UK, https://www.diamond.ac.uk/Diamond-II.html

[2] J. Kallestrup, H. Ghasem, and I. P. S. Martin, "Aperture Sharing Injection for Diamond-II", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 2606–2609. doi:10.18429/JACoW-IPAC2022-THPOPT018

[3] A. Lueangaramwong, H. Ghasem, I. Martin, and A. Morgan, "Study of aperture sharing injection scheme for Diamond-II", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 1152–1155. doi:10.18429/JACoW-IPAC2023-MOPM073

[4] C. Sun *et al.*, "Pseudo-Single-Bunch with Adjustable Frequency:A New Operation Mode for Synchrotron Light Sources", *Phys. Rev. Lett.*, vol. 109, p. 264801, Dec 2012.

[5] A. Terebilo, "Accelerator toolbox for MATLAB", Stanford Linear Accelerator Center, CA, US, Rep. SLAC-PUB-8732, 2001.

[6] "Accelerator Toolbox", ATCOLLAB, version 2.0, https://atcollab.github.io/at/

[7] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation," Advanced Photon Source, IL, US, Rep. LS-287, Sep. 2000.

[8] Y. Wang and M. Borland, "Pelegant: A parallel accelerator simulation code for electron generation and tracking," AIP Conference, pp. 241–247, 2006.

[9] R. Fielder, D. Rabusov, and S. Wang, "Updates to the impedance database for the Diamond-II storage ring", presented at the IPAC'24, Nashville, TN, USA, May 2024, paper THPC50, this conference.