ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM073

STUDY OF APERTURE SHARING INJECTION SCHEME FOR DIAMOND-II

A. Lueangaramwong*, H. Ghasem, A.F.D. Morgan, I.P.S. Martin,
Diamond Light Source, Oxfordshire, UK

Abstract

The Diamond-II storage ring has been designed to increase photon brightness by up to two orders of magnitude compared to the existing Diamond facility. A single-bunch aperture sharing injection scheme using short stripline kickers applied with high-voltage nano-second pulsers was proposed to provide both high injection efficiency and high photon beam stability in top-up mode. The quasi-transparent injection process has been optimized and studied using Accelerator Toolbox. The results of these studies will be presented.

INTRODUCTION

An aperture sharing injection scheme has been developed for the Diamond-II storage ring. In brief, the scheme uses 4 stripline kickers with a pulse duration of only a few nanoseconds to kick a single off-axis injected bunch towards the closed orbit whilst simultaneously displacing the existing stored bunch, such that the residual oscillation is shared equally between stored and injected bunches. As a result, the oscillation amplitude for the injected bunch is reduced sufficiently to allow it to be captured in the ring without losing any of the stored bunch charges. Ideally only one of the stored bunches would be affected by this scheme, however, the finite rise and fall times for the stripline kicker pulses could be long enough to perturb a few bunches on either side of the target bunch during the injection. A schematic showing the injection element locations is given in Fig. 1.

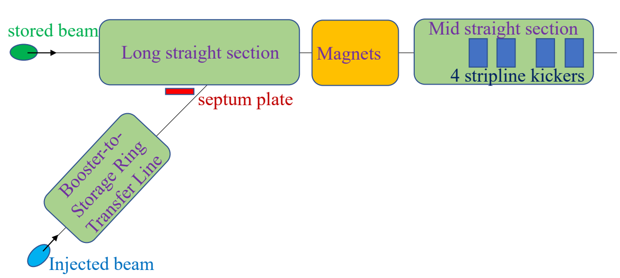

Figure 1: Schematic showing the injection element locations for the Diamond-II aperture sharing injection scheme.

When designing the injection scheme for Diamond-II, the distance between the injected beam and the septum plate in the x-axis has been set to

$$\Delta x_s = 4\sigma_x, \tag{1}$$

where Δx_s is the distance from the beam center to the outer edge of the septum plate and σ_x is the root-mean-square injected beam size in the x-axis [1].

Figure 2 shows the Diamond-II stripline kicker design in a cross section view. Using the infinite parallel plate approximation, the required voltage on each electrode to provide a kick angle θ is given by

$$V_k = \frac{\theta E h}{4l}. \tag{2}$$

In the Diamond-II set-up, the electrode length $l = 150$ mm, the electrode full-gap width $h = 14$ mm, and the beam energy in electron volts $E = 3.5$ GeV. Setting a maximum realistic voltage of 25 kV for the pulsers, the Diamond-II injection stripline kickers are able to provide a maximum nominal kick angle of 204 µrad whilst still allowing an additional 20% tuning range and operating at 80% of the power supply maximum.

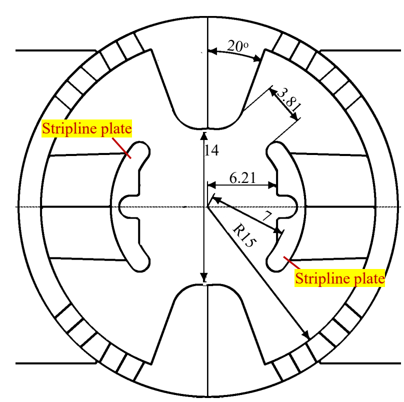

Figure 2: Cross section view of the Diamond-II stripline kicker design.

In this study, a numerical simulation has been developed with the use of Accelerator Toolbox (AT) to optimize the stripline kicker angles and injected beam parameters at the septum exit – the beam position $\langle x \rangle$ and angle $\langle x' \rangle$ along with the Courant-Snyder (CS) Twiss parameters in the x-axis – in order to minimize the overall CS-invariant after the stripline kickers, averaged over the injected and stored beam macroparticles [1]. A detailed definition of the CS-invariant calculation and the optimizer's goal can be found in [1, 2]. Simulations have been carried out including the effect of realistic optics perturbations for 20 random seeds. Particle tracking for a total of 2048 turns in the storage ring was performed using 1000 macroparticles for both the injected and stored beams.

* anusorn.lueangaramwong@diamond.ac.uk

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM073

In this paper, we present updates to the previous study [1] along with plans for hardware prototyping and the use of kickmaps for modeling the stripline kicker fields.

NEW STRIPLINE KICKER POSITIONS

The current engineering design for Diamond-II has a total of 4 stripline kickers arranged in two pairs. This is a change to the previous solution, in which all 4 stripline kickers were contained in a single vacuum tank. This change allows for synchrotron radiation absorbers to be placed upstream of each module to provide sufficient shielding for the stripline blades. Figure 3 illustrates the new layout.

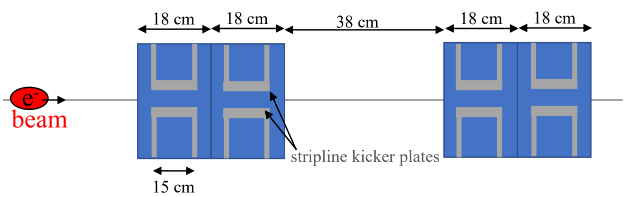

Figure 3: New stripline kicker positions.

The injected beam parameters and kick angle for each stripline kicker have been re-optimized for the new layout and latest optics solution, the results of which are shown in Table 1. The parameters are found to change by less than 1%, and both new and previous studies result in an injection efficiency of ~99% for an injected bunch with a geometric horizontal emittance of 20 nm and 10% coupling, including lattice errors and physical apertures.

Table 1: Initial Injected Beam Parameters and Kick Angles for One Stripline Kicker

Parameter	This Study	TDR Results
$\langle x' \rangle$ (µrad)	-10.9	-10.9
$\langle x \rangle$ (mm)	-5.87	-5.88
σ_x (mm)	0.22	0.22
Kick angle (µrad)	-173.8	-175.3

DROP IN BRIGHTNESS

In this section, a Figure of Merit (FoM) is used to characterize the radiation brightness and compare transparency of the aperture sharing injection method to the conventional 4-dipole kicker closed bump scheme. In the aperture sharing scheme ideally only a single stored bunch is perturbed, whereas for the conventional scheme potentially all bunches are kicked due to imperfect closure of the injection bump. The FoM used to quantify this effect is the same as used for the TDR [2] and relates to the amount of light passing through a fixed aperture set to FWHM of the photon beam a distance of 45 m from the source and integrated over a 100 µs period.

Figures 4 and 5 show the drop in brightness for sample cases of the aperture sharing and the conventional methods, respectively. The brightness drops to ~99.9% for the aperture sharing single-bunch injection and to ~12% for the conventional scheme assuming a residual perturbation of 344 µm for the electron beam. For the conventional method, the drop in brightness scales according to the size of the residual beam oscillations, as shown in Fig. 6.

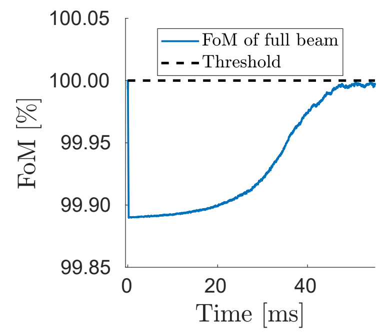

Figure 4: Drop in brightness for aperture sharing with a total kick angle of 700 µrad.

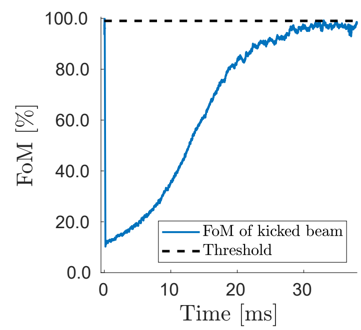

Figure 5: Drop in brightness for the 4-kicker bump with a perturbation amplitude of 344 µm.

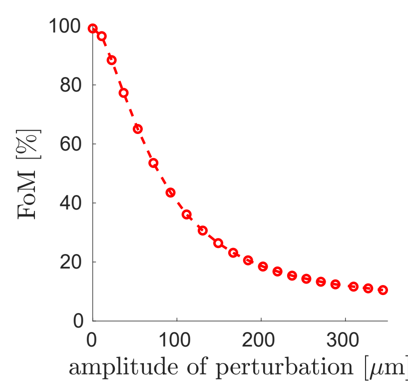

Figure 6: Plot of minimum brightness as a function of perturbation amplitude for the 4-kicker bump scheme.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM073

STRIPLINE KICKER PROTOTYPE

A prototype of the Diamond-II injection stripline kickers is currently being designed for installation in the existing facility and a prototype pulser is planned to be purchased from industry. Figure 7 shows the design of the stripline kicker prototype. The evaluation provides an opportunity to modify the designs for Diamond-II, if necessary.

Several testing stages are foreseen:

Stage 1: Lab tests S-parameter measurements will be taken to allow comparison with simulation. Port-matching will be assessed and vacuum tests performed. The pulser can be characterized for temporal profile, jitter and reliability.

Stage 2: Installation in Booster-to-Storage Ring Transfer Line (BTS) at Diamond Measurements of kick uniformity and deflection angle can be made and compared to simulation. Power reflection back to the power supply can be made along with beam induced voltage. The risk of arcing can be studied.

Stage 3: Installation in Storage Ring Beam induced heating effects and power can be measured. Impact on beam dynamics and ring impedance can be assessed.

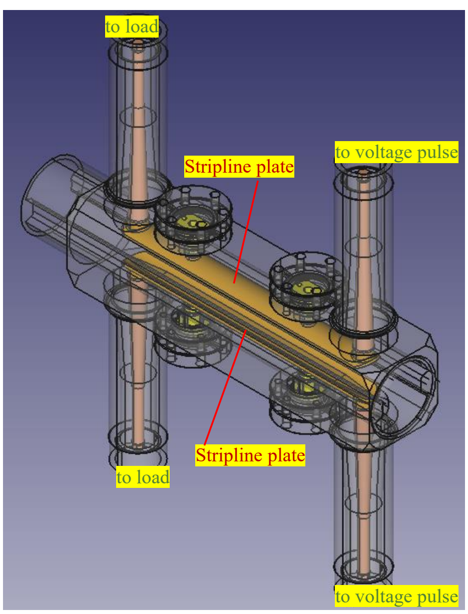

Figure 7: Design of the stripline kicker prototype.

TIME-DEPENDENT INJECTION TRACKING MODEL

A method for beam-tracking through a stripline kicker using a series of 2D-kickmaps has been developed. The electric and magnetic fields inside the stripline kicker are converted to a single kick angle that depends on position within the aperture. These, in turn, are converted to individual kickmaps for use in Accelerator Toolbox (AT) to perform beam tracking.

Given the field is time-dependent, the model takes the 3D field data at different stripline times t obtained from programs GdfidL [3] and CST Studio Suite [4]. A spline interpolation of the field as a function of stripline dimension z and time t is performed. Finally, the start time t of the kickmap is synchronized to the beam arrival time to give the maximum kick angle. Table 2 lists the parameters used in the time-dependent tracking model optimization for kick angle convergence, and an example showing the electric field in the center of the prototype stripline is given in Fig. 8.

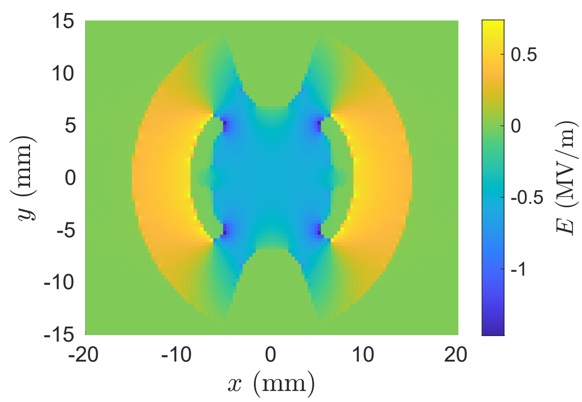

Figure 8: Sample slice of the 2D electric field (E_x) for the stripline kicker prototype obtained from program GdfidL.

Table 2: Parameters Used for the Time-Dependent Tracking model

Parameter	Value
# of kickmap elements	4500
z-step dz (μm)	40
Corresponding time step dt (ps)	0.133
Total length of model (cm)	18
Total time in model (ns)	0.6
Total length of one kicker (cm)	15

CONCLUSION

An aperture sharing injection scheme is being developed for Diamond-II. The engineering and lattice design has continued to evolve necessitating a re-optimization of the injected beam and stripline parameters. The anticipated drop in brightness has been studied by comparing the transparency between the aperture sharing and the conventional 4-kicker bump injection schemes. A stripline kicker prototype is being developed, alongside a testing plan to investigate the performance and to benchmark against numerical simulations. Lastly, a time-dependent injection tracking model has been developed to estimate the total kick angle using the simulated fields inside the stripline kicker module.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPM073

REFERENCES

[1] 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

[2] "Diamond-II Technical Design Report", Diamond Light Source, Oxfordshire, UK, 2022. https://www.diamond.ac.uk/Diamond-II.html

[3] W. Bruns, "GdfidL: a finite difference program for arbitrarily small perturbations in rectangular geometries", *IEEE Trans. Magn.*, vol. 32, no. 3, pp. 1453–1456, May 1996. doi:10.1109/20.497522

[4] Dassault Systèmes, "Electromagnetic Simulation Solvers - CST Studio Suite", https://www.3ds.com/products-services/simulia/products/cst-studio-suite/solvers/. [Accessed 27 Apr 2023]