

A NON-LINEAR INJECTION KICKER FOR DIAMOND LIGHT SOURCE

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Abstract

Ultra-low emittance lattices will operate with reduced dynamics apertures. New injection schemes are currently investigated in order to guarantee sufficient injection efficiency. A promising candidate is a pulsed kicker with a non-linear magnetic field. The studies presented in this paper prove that this kicker allows injection with reduced dynamic aperture and provide minimal perturbation of the stored beam during Top-Up injection. Plans to install such a device at the Diamond light source are outlined.

INTRODUCTION

In the framework of the feasibility studies for a Diamond upgrade to an ultra-low emittance ring, we have investigated the possibility of operating the present Diamond ring with a non-linear injector kicker. The advantages of such system over the standard four kicker bump injection are that

- it removes the complications of operating for perfect synchronization of all four pulsed magnets limit injection efficiency.
- reduce the effect of a non-perfect closed bump at the injection point can excite betatron oscillations of the stored beam circulating in the machine which are particularly detrimental during Top-Up. A perfect closed orbit bump implies a perfectly equal performance of the four kickers, which is very challenging to obtain over the whole length of the kicker pulse due to unavoidable differences in the magnets, in their chambers, in their power supplies and in their timing. Fine tuning of injection bump achieving almost identical kicker waveforms, as done as the SLS [1], reduced the injection transient to about 50 μm in both planes.
- The dynamic aperture required for the four injection kicker bump can still be significant since the closed orbit bump cannot be made too close to the septum wall. Typically 10 mm horizontal aperture is considered to be a safe margin for injection at diamond.
- A four kicker system requires space in the ring and not all rings can installed the whole injection in one straight section as shown in Fig. 1.

Several simpler designs for injection kicker have been proposed. The first attempt of using multipole magnet for beam injection started from pulsed quadrupole magnet, successfully used at the Photon Factory Advanced Ring (PF-AR) at KEK [2]. Later studies proposed a pulsed sextupole injection at Photon Factory storage ring (PF-ring) [3], and MAX-IV [4]. At BESSY-II even higher

order non-linear pulsed kicker has been used [5]. The non-linear kicker is based on a multipole magnet that has a zero magnetic field at the centre which is transparent to the stored beam. These magnets must have enough field at large amplitude away from the stored beam to kick the injected beam to be captured within machine acceptance. High order pulsed kicker are proved to be better option providing less perturbation to the stored beam. As the high order non-linear kicker provide ideal flat field for both at the centre and the injected beam, our study focus on the high order non-linear kicker.

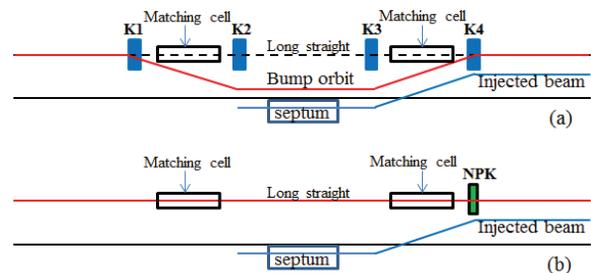


Figure 1: Schematic view for conventional injection (a) and non-linear pulsed kicker magnet (b).

NON-LINEAR PULSED KICKER BEAM INJECTION

Beam dynamics studies were performed for Diamond to identify the best position and strength of a pulsed kicker with a non-linear kick profile. The studies have to consider the available position and space. From phase advance between injection point and position of non-linear kicker close to odd number of $\pi/4$ moving toward odd number of $\pi/2$, the angle of injected beam can be reduced by pulsed kicker providing kick angle to the arriving particle in phase space. However, for high order non-linear pulsed kicker, to preserve the generated flat field at the stored beam position and to ease engineering limit for the kicker design, the peak field at the arriving injected beam position should not be too close to the centre (phase advance close to odd number of $\pi/2$).

In practice, to install the kicker in real machine, we need to compromise with beamline for available position and space even we found the best position in term of beam dynamics point of view. For Diamond, the second straight section after first DBA cell shows proper phase advance. The available position is 27 m from the injection point after an insertion device in the middle of the straight section providing the phase advance of $(9/4 + 3/20)\pi$.

To determine the exact kick angle required for injection, particle tracking which takes non-linear elements in the ring into account was performed. The first analysis of the dynamics was simplified the injected beam with a single particle. The AT tracking code allows the determination of the coordinates (x_{pm}, x'_{pm}) of the particle at the position of the pulsed kicker magnet.

SINGLE PARTICLE TRACKING

The pulsed kicker was modelled into the ring at the right position from its generated kick map. The injected particle after septum magnet was generated with the initial coordinate of -20 mm horizontally off-axis. The particle coordinates was followed in six-dimension phase space at each element. The horizontal position and angle of the arriving particle at the kicker position indicates the required magnetic field and its peak position horizontally. It is important that the peak position should not be too closed to the nominal beam otherwise the flat field range of the pulsed kick will be shortened and some part of the stored beam can be excited by the pulsed kicker during injection. The peak position is also limited by the smallest distance of the wires and the narrowest vertical aperture that can be engineered.

The arriving position and angle of injected particle can be controlled by injection with initial angle in horizontal plane. For Diamond, to adjust the injected particle to arrive at -7.45 mm from centre, the initial angle for injection is -1 mrad. The required kick is 2.2mrad to maximized the injection efficiency (minimize injection invariant). From the required kick angle (θ_{kick}) , the required magnetic field can be calculated from

$$B = \frac{\theta_{kick} \times (B_0 \rho)}{L} \quad (1)$$

where L is pulsed kicker's magnetic length and $B_0 \rho$ is machine rigidity.

First turn tracking revealed the particle trajectory as shown in Fig. 2 considering the effect of the non-linear pulsed kicker.

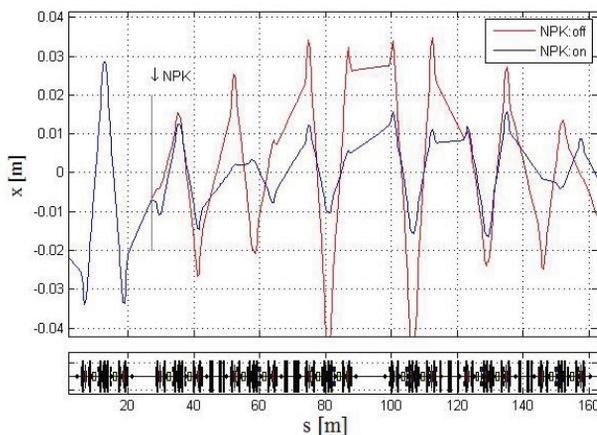


Figure 2: First turn tracking for injected particle with and without non-linear pulsed kicker.

Obviously, when the non-linear pulsed kicker was turned on (beam injection), the particle's amplitude can be reduced significantly after passing through the kicker throughout the ring. The injected particle was kicked into acceptance as shown in Fig. 3 by the generated magnetic field of the non-linear kicker as shown in Fig.4. On the other hand, the trajectory when the pulsed kicker was turned off showed much larger amplitude.

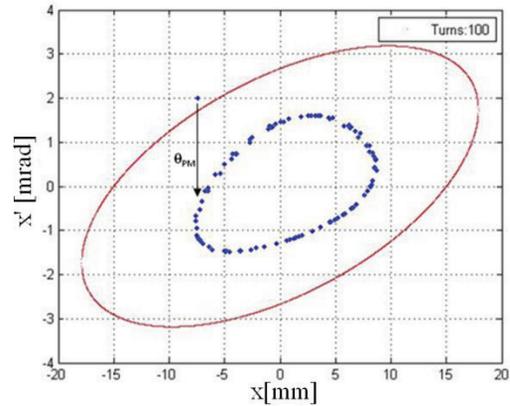


Figure 3: Single particle tracking for 100 turns at the position of the pulsed kicker magnet.

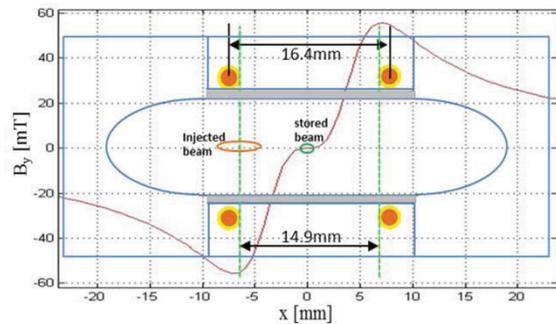


Figure 4: Schematic view of non-linear kicker with respect to magnetic field amplitude.

Table 1: Non-Linear Pulsed Kicker's Parameters

| Description | Parameter |
|------------------|-------------------------------|
| Peak field | 55 mT |
| Deflection angle | 2.2 mrad |
| Magnetic length | 400 mm |
| Aperture (h/v) | 72mm / 8.2mm |
| Pulse length | 3.73 μ s, half-sinusoidal |
| Required current | 710 A |

MULTIPLE PARTICLES TRACKING

From single particle tracking, we obtain the best position and required kick for particle capturing. The ideal behaviour of the particle associated with the non-linear pulsed kicker was demonstrated. Multiple particles of the injected bunch can provide more realistic situation for beam injection. A Gaussian distributed bunch of a thousand particles was generated from the end of booster. Similar to the single particle study, the injected bunch with 150 nm-rad beam emittance was injected at the distance of -20 mm off-axis with initial angle of -1 mrad.

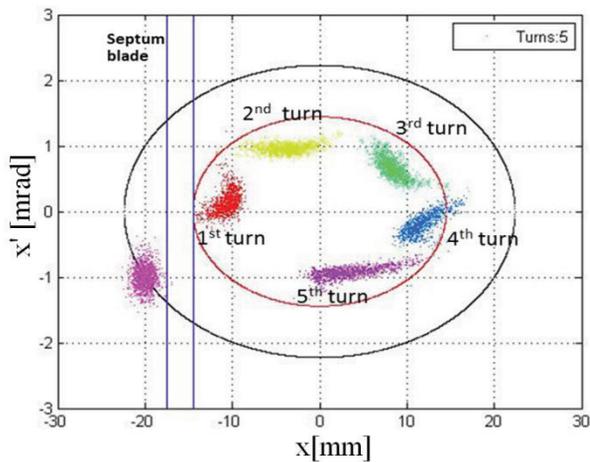


Figure 5: Five turns tracking at the position of injection.

The beam was tracked from the injection point along the ring for several turns. Then beam loss was recorded after a hundred turns and injection efficiency can be calculated. The main beam loss caused by beam collision with the acceptance defined from septum blade of 3 mm thick. The first five turn tracking in phase space is shown in Fig. 5. More than 99% of injection efficiency is comparable with the conventional injection with four kicker using at Diamond. The non-linear pulsed kicker's parameters required for beam injection are summarized in Table 1.

From multiple particles tracking study, if the position of non-linear kicker is too far from the injection point, the arriving beam will obviously be distorted because of non-linear field at large amplitude leading to low injection efficiency. Injected beam emittance can also affect the injection efficiency because too large injected bunch arriving at the excited field of non-linear pulsed kicker which has limited flat peak will experience different kick and be distorted.

EFFECT ON THE STORED BEAM

To study the effects of non-linear pulsed kicker on the stored beam, we compared with the effects from pulsed quadrupole injection. Assuming the stored beam's horizontal emittance of 2.75 nm-rad and beam size (σ_x) of 0.45 mm, the stored beam was tracked through the centre of the ring for one turn with the same injection condition as used for kicking the injected beam off-axis (excite the pulsed kicker only the first turn). The effects of the kicker can be investigated from the perturbation of the beam at the position just after the kicker with respect to the nominal beam without perturbation (no pulsed kicker). As shown in Fig. 6, the non-linear pulsed kicker shows no effect on the stored beam while in pulsed quadrupole injection the stored beam was clearly perturbed as the shape of the beam in phase space was obviously changed with respect to the no excitation situation. This proves the advantage of non-linear pulsed kicker for top-up injection providing transparent excitation to the stored beam.

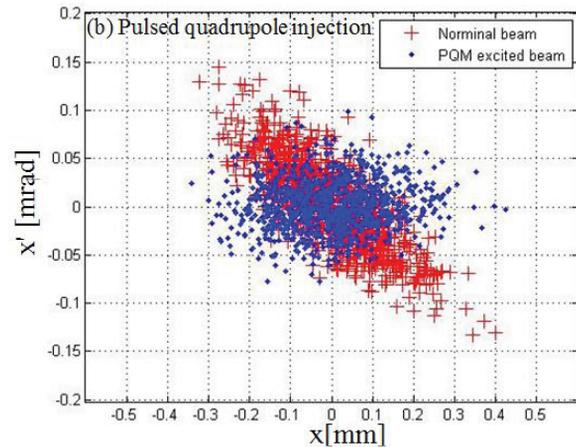
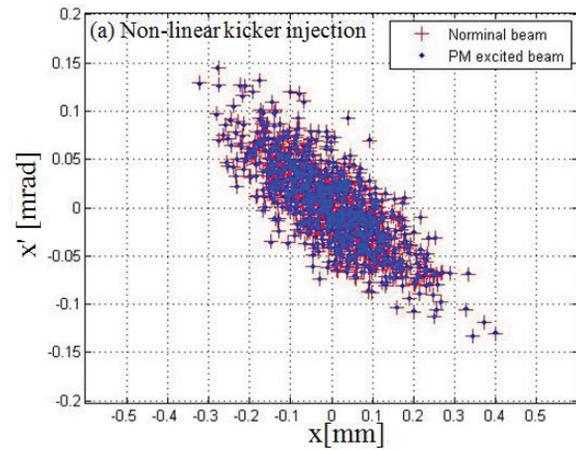


Figure 6: Effect from pulsed magnets on stored beam during injection at the position of pulsed magnets.

CONCLUSIONS

The beam dynamics study with a high order non-linear pulsed kicker installed at the available position in the ring show excellence performance of high injection efficiency. No perturbation on the stored beam can be observed during injection. We plan to install the non-linear pulsed kicker in Diamond soon.

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