STUDY ON INJECTION WITH PULSED MULTIPOLE MAGNET FOR SPS STORAGE RING

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Abstract

Pulsed multipole magnet (PM) has zero magnetic field at the centre, therefore it introduces no perturbation to the stored beam. It has been demonstrated that this injection scheme is able to minimise the oscillation of the stored beam, and thus make it suitable for top-up operation. To investigate the suitability of employing this injection method at Siam Photon Source, PM was modelled and optimised for the best performance using particle tracking based method. This work presents injection optimisation process with PM considering various constraints such as position of injected beam, injection conditions, and effects of the installed IDs.

INTRODUCTION

Most storage rings in operation employ conventional beam injection using dipole kickers to generate closed orbit bump. The stored beam is moved closer to the septum magnet to accept the injected beam into machine acceptance. Disadvantages of the conventional injection process are well known. It requires considerable space in the ring to accommodate up to four kickers, complicated control system, and others. To create a perfect closed orbit bump is proved to be very challenging which require equally perfect performance of all the kickers. Unavoidable perturbation to the stored beam is the main drawback for conventional scheme in top-up operation in particular since it leads to unfavourable fluctuation of photon flux at the experiments.

Several storage rings are now using or planning to use multipole magnet for beam injection. Unlike dipole, multipole magnet has zero field at the centre where the stored beam will be. The concept was first demonstrated using pulsed quadrupole magnet (PQM) [1] and later pulsed sextupole magnet (PSM) [2]. The higher order of the multipole the flatter the field at the centre. Thus in this study we focus exclusively on the BESSY-II type pulsed multipole magnet [3], [4] which has the field shape similar to that of octupole magnet. The main structure of the pulsed kicker has four parallel wires where the stored beam will be at the centre. It is very simple compared to the conventional system. For Siam Photon Source (SPS) storage ring, top-up operation is the main goal for delivering constant photon flux and improve the thermal stability of the machine and beamline optics after full energy injection at 1.2 GeV in the near future.

BEAM INJECTION AT SPS

Currently the SPS storage ring employs conventional beam injection process using closed orbit bump with three bump magnets situated in different straight sections in the ring due to space limitation. This is not ideal for beam injection because the bumped orbit will be affected by other components between the bump magnets.

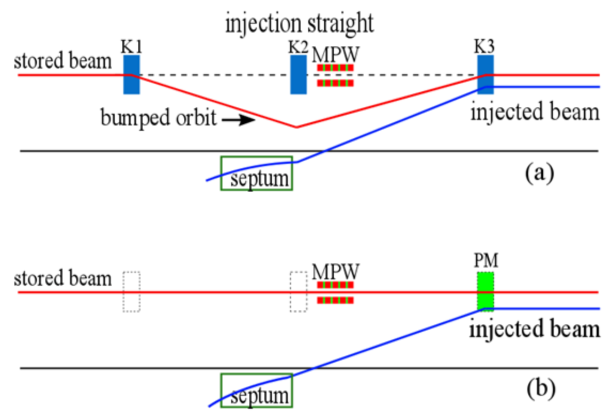

Figure 1: Schematic view of the injection system with conventional 3 kickers (a) and a single pulsed multipole magnet (PM) (b).

Since the SPS storage ring is a small (81 m circumference) ring equipped with only 4 straights, we have to utilize all of them for IDs. A 2.2 T multipole wiggler (MPW) was installed in the injection straight right after the septum magnet, as shown in Figure 1 (a). Due to this configuration, the injected beam will pass through the MPW and be kicked outward if the MPW's gap is fully closed. This is inconvenient for machine operation since for every injection the MPW gap has to be opened. Particle tracking using the MPW kickmap confirmed that the injected beam would indeed be kicked out when the MPW gap is closed. To improve the injection process and realize top-up operation, we have to investigate a new injection method.

PULSED MULTIPOLE MAGNET

Figure 1 (b) shows the beam injection scheme with a single PM which is much simpler than the conventional scheme with three bumps. It is possible to analytically calculate the required condition for single turn injection. However, to expedite the investigation and to be able to apply more realistic injection conditions, particle tracking code, Accelerator Toolbox (AT) [5] was employed. Kickmap describing the property of the PM was modelled and implemented in the tracking codes. The distance between the injection point and the position of the PM has to be sufficient considering phase advance of about odd number of $\pi/4$. The possible location of the PM in our case is at the last existing bump magnet (11.4 m). Hence we might need to replace the bump magnet with the PM.

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Tracking Based Optimisation

AT accelerator model was used to directly optimise the injection efficiency with the PM. The optimisation particle tracking has two steps:

1. Single particle tracking is used to search for injection position and angle (x_{inj}, x'_{inj}) of the injected beam. This allows the exact position and angle of the injected particle arriving at the PM (x_{pm}, x'_{pm}) to be determined. Figure 2 shows the injected beam position and angle arriving at the PM when the injection amplitude is -43 mm. The injection angle of about 1 mrad allows the injected particle to arrive at the PM with horizontal position of about 7 mm which will determine the distance between the wires of the PM.
2. Multiple particles tracking is used to find the best PM kick angle. The same injection condition found in the first step and parameters in Table 1 were used to generate a Gaussian beam of 1000 particles. PM kick angle was varied and a new kickmap was generated. Then the injected bunch was tracked for 1000 turns while the kick from the PM was applied for the first turn only. The best solution will be used in the next step.

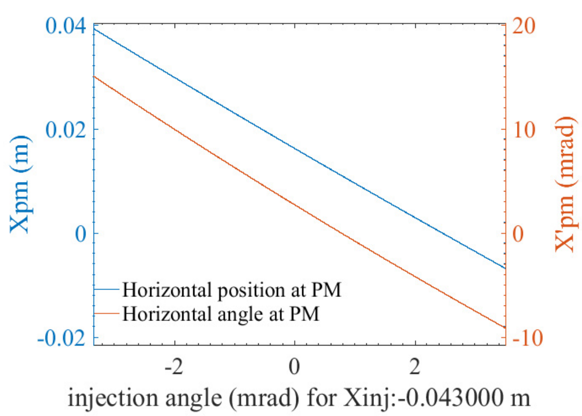

Figure 2: Position and angle of injected beam at the PM as a function of the injection angle.

Table 1: Injection Parameters

Parameter	
Injected beam	
Horizontal emittance	406.8 nm.rad
Vertical emittance	40.6 nm.rad
Bunch length	14.75 mm
Injection position	-43 mm
Injection angle	1.23 mrad
PM position	11.4 m
PM kick angle	4.5 mrad

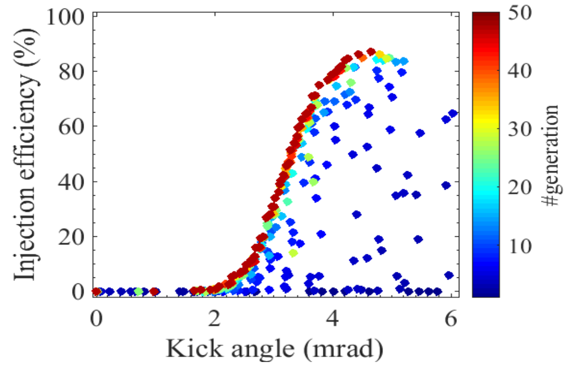

Figure 3: Pareto front of injection efficiency and kick angle optimisation with MOGA.

Optimisation with MOGA

Further optimisation after the tracking based method was performed using more advanced algorithm. Multi Objective Genetic Algorithm (MOGA) is very useful for conflicting objectives giving a trade-off optimal solution front. In this case, we try to reduce the applied kick angle and increase injection efficiency. Matlab based genetic algorithm [6] was used with AT model. The steps of the optimisation are as follows:

1. Injected beam was generated from the parameters in Table 1.
2. The beam was tracked for one turn with the pulsed kicker turned on.
3. From second to thousandth turn, the pulsed kicker was turned off.
4. Objective function (injection efficiency) was calculated from the number of the remaining particles.

Variables used in the optimisation were injection angle and kick angle introduced by the pulsed kicker. The optimal front (red dots) after the optimisation of 50 generations is shown in Figure 3. The injection efficiency of 87% can be achieved with the injection angle of 1.23 mrad and PM kick angle of 4.5 mrad. From the optimal front, weaker kick gives lower injection efficiency. The distance between the wires of the PM can

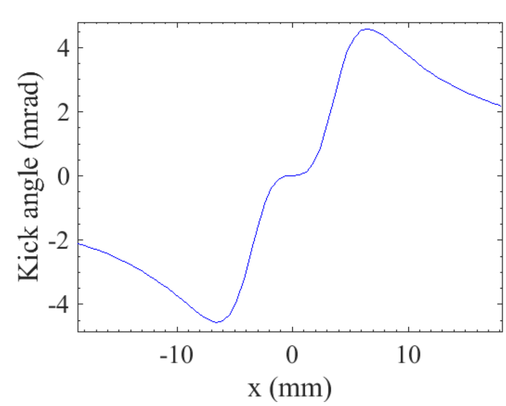

Figure 4: PM's kick angle as a function of position.

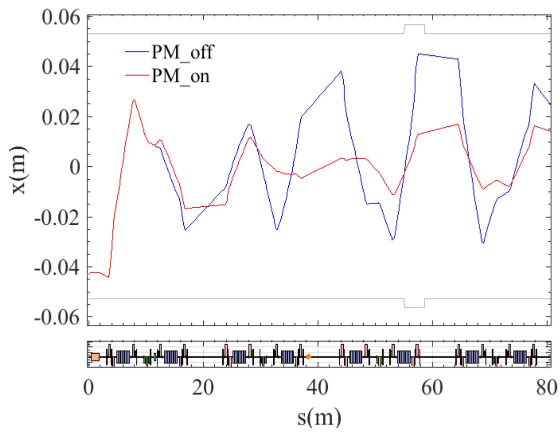

Figure 5: Injected particle first turn trajectory.

be used also as one of the variables and it was found that the solution with smaller distance between the wires is more preferable, leading to better injection efficiency. However, smaller distance between the wires requires narrower beam pipe which might limit the beam lifetime and cause thermal problems.

The result of the optimisation provides the PM with the kick angle, as shown in Figure 4, giving the best injection efficiency when the distance between the wires in the PM is fixed at 14 mm. It is clear that the flat field at the centre could minimize the perturbation on the stored beam. The PM also gives flat field off-axis about 7 mm where the injected beam will experience the kick. This could deliver more uniform kick to the injected beam compared to PSM and PQM. The trajectory of the injected particle with and without the PM is shown in Figure 5. The trajectory amplitude reduction is significant when the PM is in use. Figure 6 shows the phase space of the injected beam for the first 5 turns. Noticeably, the shape of the injected beam was perturbed by the provided kick because of the large horizontal injected beam size. This leads to injection lost and lower injection efficiency. With smaller beam this injection scheme could perform better.

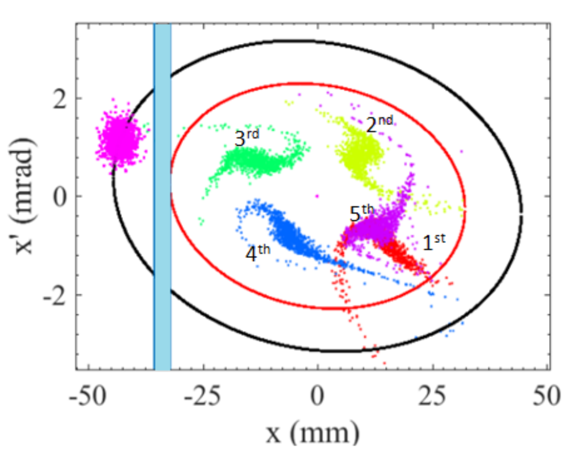

Figure 6: Injected beam phase space at injection point for the first 5 turns.

EFFECT ON THE STORED BEAM

The stored beam was tracked through the PM for one turn to see the effect of the PM. Phase space coordinates of the beam were recorded with and without the PM kick then the comparison is plotted in Figure. 7. If there is no perturbation on the stored beam the red and blue markers in Figure 7 should completely overlap. However, particles in the large beam receive kick from the PM depending on the horizontal position (according to the field shape in Figure 4). Although the beam was partially perturbed by the kick at large amplitude, its centroid was not affected by the PM.

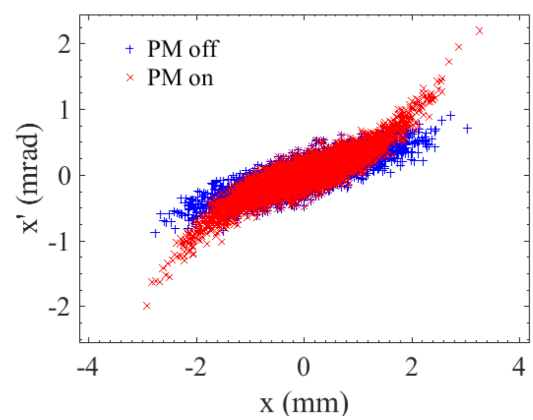

Figure 7: Stored beam phase space affected by the PM.

CONCLUSION

The PM scheme provides a promising solution for beam injection with existing MPW at narrowest gap. Tracking based MOGA optimisation is effective and gives us a broader view of optimal solutions. Injection efficiency of about 87% is operable and can be improved further by reducing the injected beam size and bunch length. The effect of the PM on the stored beam is noticeable but still small. The new injection scheme could allow us to operate with top-up mode in the near future.

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