IMPLEMENTATION OF A DC BUMP AT THE STORAGE RING INJECTION STRAIGHT SECTION*

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Abstract

The NSLS II beam injection works with a DC septum, a pulsed septum and four fast kicker magnets. The kicker power supplies each produce a two revolution period pulsed field, 5.2µs half sine waveform, using ~5kA drive voltage. The corresponding close orbit bump amplitude is ~15mm. It is desired that the bump is transparent to the users for top-off injection. However, high voltage and short pulse power supplies have challenges to maintain pulse-to-pulse stability and magnet-to-magnet reproducibility. To minimize these issues, we propose implementing a DC local bump on top of the fast bump to reduce the fast kicker strength by a factor of 2/3. This bump uses two storage ring corrector magnets plus one additional magnet at the septum to create a local bump. Additionally, these magnets could provide a DC bump to simulate the septum position effects on the store beam lifetime. This paper presents the detail design of this DC injection bump and related beam dynamics.

INTRODUCTION

The NSLS-II [1] is a 3 GeV third generation synchrotron light source under construction at Brookhaven National Laboratory. Due to its short lifetime, NSLS-II storage ring requires the top-off injection (once a minute) to keep the storage ring current constant to +/- 1%.

The design emittance of the ring results in extremely small beam size and even a small disturbance, from the storage ring pulsed magnets (four kickers and pulsed septum) at the injection straight line, would excite the stored beam betatron oscillation and perturb some user experiments. As a consequence, the ring kickers have to be extremely well characterized to make the bump magnets' mechanical placement to high accuracy and very tight requirements to maintain pulse-to-pulse stability and magnet-to-magnet reproducibility. Also, the pulse septum field has to be well shielded to control the leakage field integral at µT-m range.

The kicker nominal drive voltage is ~ 5 kV to generate a 15mm close orbit bump in 5.2 µs. Experiences show that the power supply is more stable at lower voltage operation. We propose to implement a DC local bump on top of the fast bump to reduce the fast kicker strength by a factor of 2/3. This DC bump uses two ring corrector magnets plus one additional magnet at the septum to create a local bump. Besides the improvements on kicker's stability and reproducibility, it also releases the kicker's tilt error and timing error tolerance based on scale law [2]. As a side benefit, the DC bump can be used to study the effects of the reduced SR aperture on the stored beam lifetime.

In this paper, we show the DC bump design, its effect on the injection efficiency and stored beam lifetime, and the DC magnet design at the septum.

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OPTIMAL INJECTION

The NSLS II storage ring injection system consists of four kickers, producing a closed bump for stored beam, a DC septum and a pulsed septum for beam injection, fitted in a 9.3 m long straight section. The four kicker magnets, K1 to K4, are placed symmetrically in the straight section. Their bending angles are the same, but different bend direction. The stored beam gets the maximum bump amplitude, at the middle of injection straight line.

When the injected beam arrives, kickers K1 and K2 kick the stored beam towards the septum knife by 15 mm. The stored beam and the injected beam merge at the exit of the septum. Kickers K3 and K4 will kick both of the trains, so that the stored beam returns to its designed orbit, and the injected beam is off-axis. The injected beam and stored beam relative position at the exit of septum is shown in figure 1. The designed stored beam equilibrium orbit is 17.5 mm away from septum knife, so there are 2.5 mm safe region to the septum knife for the bumped beam. Their distance after septum, due to the septum knife thickness, the beam size and safe region, is equal to the injected beam off-axis distance, which is that the smaller, the better injection efficiency. The designed stored beam and injected beam center distance is 9.5 mm, which is very hard to be smaller.

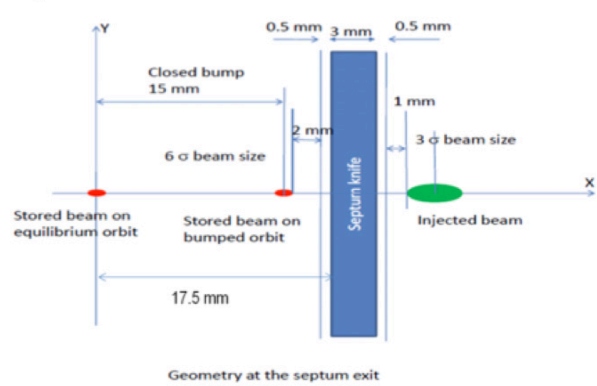

Figure 1: Injected beam and stored beam relative position at the exit of septum.

DC LOCAL BUMP

Three DC correctors are used as a local bump to lower the fast bump kick strength to improve the fast bump

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stability and reproducibility. Fig. 2 shows arrangement of the three DC bump correctors. The middle corrector is integrated into the pulsed septum upstream end. Two other correctors are located on the storage ring girders before and after the injection straight section. In between them, there are two quads and two sextupoles, which induce small tune shift when the DC bump is on, but can be corrected.

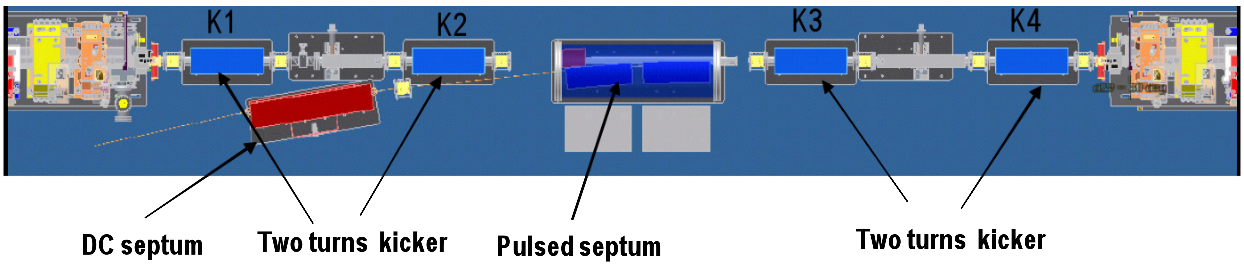

Figure 2: The layout of DC bump at the injection straight line.

Fig. 3 shows the stored beam trajectory through the injection straight region in different scenarios of the DC bump. The black line shows the beam trajectory with the DC bump on and the kickers off. The green line corresponds to the beam trajectory with the fast bump on and the DC bump off. The red line, DCfs1, is the beam trajectory with the both bumps on. There the kicker strengths are optimised so that the beam trajectory along the septum is parallel to the septum knife. The blue line, DCfs2, corresponds to the situation when four kickers have the same strength.

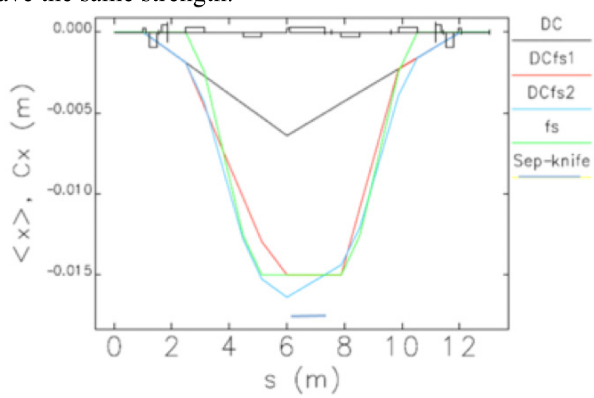

Figure 3: Beam center for different scenario of bump(DC: DC bump only; DCfs1: DC bump and fast bump with different bump amplitude; DCfs2: DC bump + fast bump with equal bump amplitude; fs: fast bump only).

Fig. 4 shows the injected beam and stored beam phase space at septum position for the case of fs and DCfs1. The red line is the septum position. The red dots are the stored beam. The black dots show the injected beam before injection and the first few turns after injection. The upper picture shows the case with fast kickers only, where the stored beam equilibrium orbit is (0, 0) and the injected beam oscillates around it. The lower picture shows the case with DC and weaker fast kickers, where the stored beam equilibrium orbit is determined by the DC bump and the injected beam oscillates around the stored beam equilibrium center.

The combining effect of DC and fast bump is equivalent to the baseline fast bump. The stronger DC local bump, the looser requirement on fast kick bump. There are limitations on DC bump amplitude, including the injected beam capture efficiency and the stored beam lifetime.

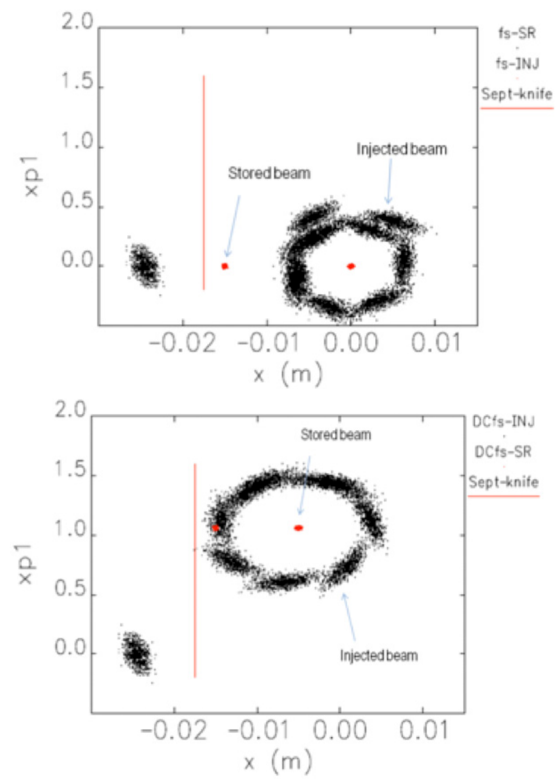

Figure 4: Beam phase space without and with DC bump at septum.

BEAM DYNAMICS

Injection Efficiency Study

Fig. 4 shows that the injected beam will get lost if the DC bump is too strong.

Elegant [3] is used to simulate different DC bump amplitudes on the injection efficiency. The input lattice has a set of random errors with orbit correction. Tracking takes into account the synchrotron radiation and turns on the RF system. The injected beam is 9.5 mm off-axis. The

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DC bump amplitude changes from 3.5mm to 7.5 mm. It tracks 1000 particles up to 500 turns, which is 4 periods of storage ring synchrotron oscillation. Simulation shows that after 100 turns, the transmission ratio does not change.

In figure 5, it shows the injected beam transmission ratio in the first 150 passes. The injection efficiency is ~ 68% if the beam is kicked by 7.5 mm. If the beam is bumped by 5mm, the injection efficiency would maintain ~ 99.7%.

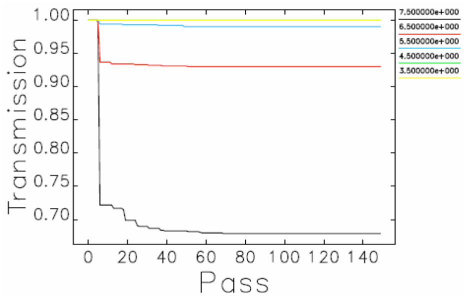

Figure 5: The injected beam transmission ratio change with DC bump amplitude.

Stored Beam Lifetime

The stored beam equilibrium orbit is closer to the septum with the local DC bump. This affects the stored beam lifetime. Figure 6 shows the stored beam lifetime change as the function of the DC bumped amplitude. It shows that the stored beam lifetime could keep more than 3 hours for the bumped amplitude up to 9.5 mm. The stored beam lifetime is not limited by the septum knife if the bumped amplitude is less than 5.5 mm.

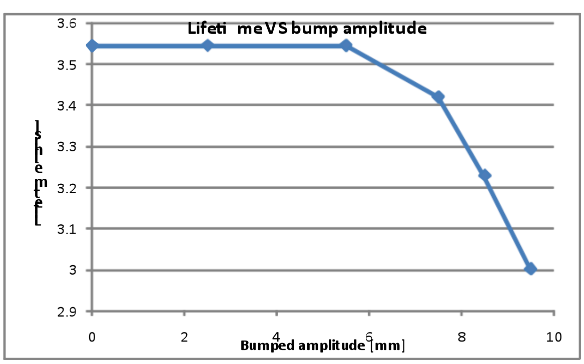

Figure 6: Stored beam lifetime change with the distance between stored beam and the septum knife.

The maximum local DC bump amplitude is designed to be 5mm. The needed middle DC bump strength is 2.35 mrad and the outer bump strength is 1.2 mrad. These three bumps' maximum strength is 2.5 mm with overhead and orbit correction capability. The 5mm local bump effects on the dynamic aperture for on-momentum beam was also studied and has no effect. The maximum beam center change at quadrupole is 0.7mm and at the sextupole is 1.26 mm. The higher order effects from two pairs of quads and sextupoles on the close orbit is negligible.

MAGNET DESIGN

Conventional magnet designs can be used for the bump dipoles except for the in-vacuum septum case where the middle bump dipole is inside the vacuum system. For an in-vacuum bump dipole, a proof-of-principle concept is illustrated in Fig. 7. Here we use C-magnet geometry with a thin, upright coil structure that is contained inside a vacuum tight aluminium enclosure. The vertical coil's vertical extent is set to keep the coil's current density and heat dissipation low enough that conduction cooling via the aluminium enclosure to a heat sink is adequate to stabilize the magnet temperature. The coil lead pair is brought outside the vacuum chamber via a feed through attached to the coil enclosure.

The in-vacuum yoke must have a wide pole to accommodate the bumped and normal circulating beam trajectories. The main yoke has an external field clamping plate with all dimensions chosen to avoid excessive field saturation so that the external field near the pulsed septum yoke is only a fraction of a gauss.

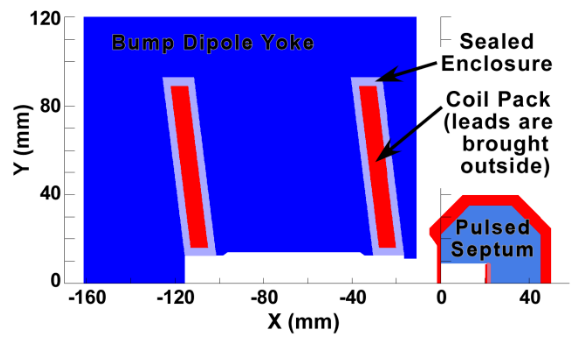

Figure 7: Corrector profile.

SUMMARY

The scheme to implement a DC local bump at the injection straight region is studied. The bump amplitude is 5 mm to maintain the high injection efficiency and stored beam lifetime. The required bump strength is 2.5 mrad. By doing this, the fast bump strength reduces by a factor of 1/3. The corresponding the error tolerance is 1.5 times bigger. The fast bump system stability and reproducibility will be improved by operating at low driven voltage.

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