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Alternative Designs for the NSLS-II Injection Straight Section

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ALTERNATIVE DESIGNS OF THE NSLS-II INJECTION STRAIGHT SECTION

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Abstract

Brookhaven National Laboratory (BNL) is developing a state-of-the-art 3 GeV synchrotron light source, the NSLS-II [1]. The 9.3 meter-long injection straight section of its storage ring now fits a conventional injection set-up consisting of four kickers producing a closed bump, together with a DC septum and a pulsed septum. In this paper, we analyze an alternative option based on injection via a pulsed sextupole magnet. We discuss the dynamics of the injected and stored beams and, subsequently, the magnet's specifications and tolerances. We conclude by summarizing the advantages and drawbacks of each injection scheme.

INTRODUCTION

The design initially considered for the injection straight section of the NSLS II was the conventional four-kicker bump scheme. Recently, another possibility was proposed for storage ring injection using a pulsed multipole [2]. This offers the opportunity of reducing the number of pulsed magnets in the ring, thereby increasing the accelerator's overall reliability. However its main advantage is that in the absence of the closed orbit bump, less perturbation is induced on the stored beam, which is passing through the center of the multipole field.

We analyzed and compared the both schemes for the NSLS-II storage ring (Fig. 1).

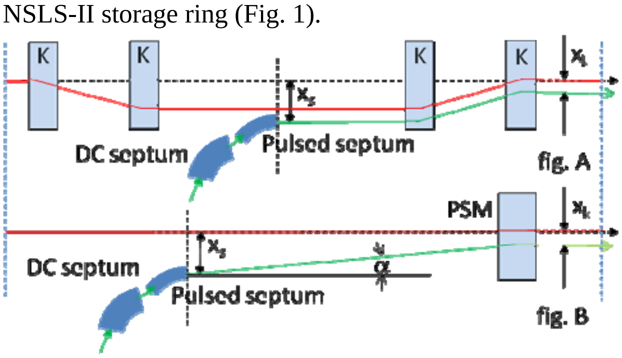

Fig. 1: Comparison of the two injection schemes (red indicates the stored beam, green is the injected beam). Fig, A is the conventional 4-kicker scheme and fig. B is the pulsed sextupole magnet (PSM) scheme.

During analysis, we assumed the following constraints to both schemes:

- Those imposed by the flexibility of the booster-to-storage-ring transport-line (BSR TL) and
- layout of storage ring's injection straight section
- fixed angles and coordinates of the injected and stored beams at the exit of the septum
- fixed angles and coordinates of the injected and stored beams at the exit of the septum (the same requirements on the storage ring's Dynamic Aperture needed for injection for the both schemes)

The last two requirements translate into the same separation between the injected and stored beams at the septum (x_s=25 mm), and at the exit of the injection straight section (x_k=8.5 mm). Figure 2 compares the injected beam's motion in phase space for these two schemes.

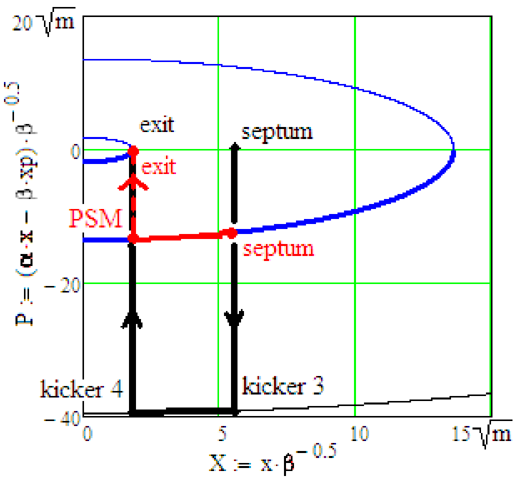

Fig. 2: Injected beam's motion (black – 4 kicker scheme; and, red – PSM scheme) in the normalized phase space coordinates with respect to the storage ring's orbit.

Furthermore, the Touschek scattering in stored beam places restrictions on the minimum horizontal physical aperture necessary at the pulsed magnets, resulting in 18 mm at the septum, and 20 mm at the pulsed multipole.

We have considered a pulsed quadrupole magnet as the injection kicker. We concluded that the quadrupole will induce focusing on the stored beam strongly perturbing its size and interrupting user experiments [3]. Thus, we chose the pulsed sextupole magnet as the candidate for the NSLS-II injection scheme.

Figure 3 shows the layout for the 4-kicker scheme- and for the PSM scheme.

Since x_k is kept the same in both schemes, it is advantageous to maximize the distance between the septum and PSM thereby reducing the PSM's strength. However, this is limited by the available space in the injection straight section.

We strived to maintain the position and the angle of the trajectory at the entrance into the DC septum close in both cases to prevent gross modifications of the BSR TL.

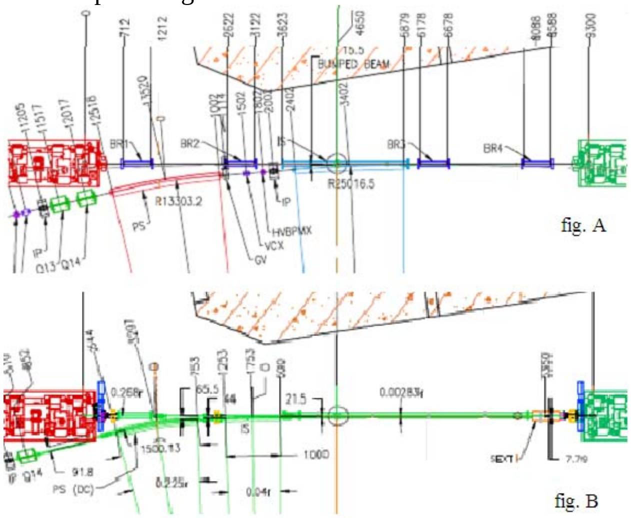

Fig. 3: Storage ring layouts for (a) the 4-kicker scheme, and (b) the PSM scheme.

Similarly, for both, we considered the waveforms of the pulsed magnets to be two turns long (5.2 μs), so the injected beam will not encroach upon the pulsed magnet field on its second turn.

The two options are presented separately below in some detail.

FOUR-KICKER BUMP

The four-kicker bump is a conventional injection scheme as adopted by many facilities. The NSLS-II's storage ring features long straight sections (9.3 m between the yokes of the outer quadrupoles) that offer the benefit of fairly low kicker's field [4]. We split the injection septum into two parts – DC and pulsed – thereby minimizing the strength of the pulsed magnet to ease its design and moderate its tolerances. We also considered installing weak kickers for correcting the non-closure of the kicker bump. The following table lists the pulsed magnet parameters for this layout:

Parameter	DC septum	Pulsed septum	Kicker	Weak kicker
Length, m	1.8	2	0.5	0.2
Field, T	0.833	0.42	0.165	0.053
Angle, mrad	150	80	8.5	1
Aperture x/y, mm	50/20	20/15	60/27	60/30
Pulse shape/width, μs	n/a	sine 100	½sine 5.2	½sine 5.2
Flatness/ Field Error tolerance, %	n/a/ 0.03	0.2/0.2	8E-3 (amp)	1E-2
Align. tol., μm/μm/mrad	100/10 0/0.2	100/10 0/0.2	1.2E-5 vertical	1E-2
Inductance, μH	n/a	3.35	1.4	0.5
Current, kA/ Voltage, kV	1.6E3 at/0.06	5.5/ 1.16	4.2/ 3.7	1.4/ 0.45

Table 1: Pulsed magnet parameters for the 4-kicker bump injection scheme (at=ampere turns).

We analyzed tolerances in two ways. We found the tolerances for the kicker's roll and kicker's amplitude mismatch analytically in a similar way as the approach described in [5] that was developed for an arbitrary bunch in the storage ring bunch train and uses realistic kicker waveforms. In addition, we tracked particles through the complete storage ring lattice to study the same effects of the kicker's errors. From this analysis, we calculated the deviations from the closed orbit in position, and in an angle in the ID source points corresponding to the centers of the straight sections around the ring (Fig. 4).

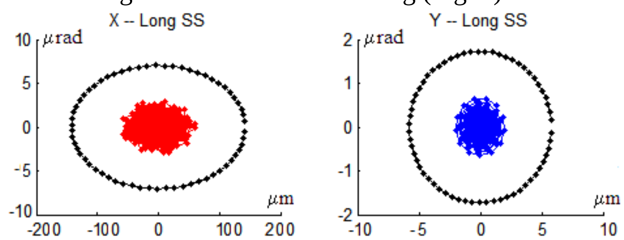

Fig. 4: Horizontal (left plot) and vertical (right plot) deviations in position and angle of the stored beam central orbit in the centers of the long straight sections for multiple seeds of the kicker's errors. Consecutive points on the plots correspond to consecutive ID source points around the ring. The black ellipse is defined by the rms of the stored beam's size and divergence at source points.

From these studies, we identified strict requirements of keeping the orbit's transient due to kicker errors below 10% of the rms of the stored beam's size and divergence (Table 1). This problem is exacerbated by requirement of having the kicker waveforms matching each other at every instant of time.

We will address the feasibility of these tight tolerances in modeling, designing, and testing the magnet prototypes.

PULSED SEXTUPOLE MAGNET

Following the geometry in Fig. 2, we optimized the PSM parameters. Quality merit is illustrated in Fig. 4 as the ratio of the two circles that corresponds to the reduction of the amplitude of residual betatron motion of the incoming beam by the PSM.

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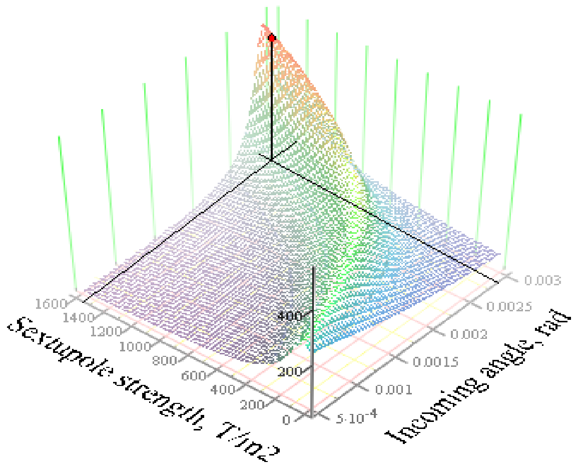

Fig. 5: Inverse of the residual betatron oscillation amplitude as a function of the entrance angle at the sextupole (α in Fig. 1), and required sextupole strength. The red dot (top middle) corresponds to the solution chosen for the NSLS-II layout.

A decrease in residual oscillation amplitude leads to an increase in sextupole strength, which affects the specifications for the magnet and the power supply. The inductance of the PSM magnet can be minimized by reducing the field volume while maintaining a reasonable pole tip field value [6]. (Fig. 6).

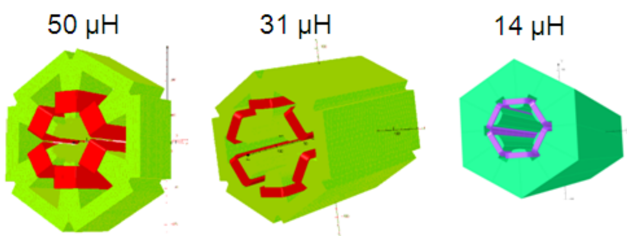

Fig. 6: Optimization of pulsed sextupole magnet (not to scale). Magnet inductance is indicated above.

Table 2 lists our choice of the PSM parameters for the injection straight section's geometry (shown in Fig. 3),

Parameter	DC septum	Pulsed septum	PSM
Length, m	1.5	1	0.5
Field or gradient	1.5 T	0.4 T	1550 $T{\cdot}m^{-3}$
Angle, mrad	225	40	2.8
½ aperture, mm	5/20	20/15	25/25
Pulse shape/width, µs	DC	sine/100	½ sine 5.2
Flatness/ Field Error tol., %	n/a	0.2/0.2	<1
Align. tol., µm/µm/mrad	100/100/ 0.2	100/100/ 0.2	100/10/1
Inductance, µH	n/a	3.35	14
Current, kA/ Voltage, kV	26400at/ 0.083	5.25/ 0.56	3.2/ 27

Table 2: Pulsed magnet parameters for the PSM injection scheme.

From a similar tolerance analysis as for the 4-kicker layout, we established that the stored beam's orbit is very sensitive to the vertical alignment of the PSM (Table 2). In order to maintain the stored beam orbit within 10% of the beam size in the source points we must control the PSM vertical alignment within 10 microns. This will require developing a dedicated beam positioning system with BPMs and monitoring, together with correction by the Fast Orbit Feedback system. We plan to build a PSM prototype to study the feasibility of meeting this tolerance.

Additionally, the PSM induces strong focusing on the injected beam that passes off the magnet's axes. For the NSLS-II, this effect is comparable to the maximum gradient of a single quadrupole in the BSR TL. To account for this effect, we modified the layout of the transport line, and found an optical solution that matches the injected beam's Twiss parameters to their optimal values at the entrance of the PSM [7]. As this effect strongly depends on the injected beam's trajectory, it will be critical to maintain routinely trajectory stability at the PSM to the level of hundred microns, to maintain optimum optics matching.

Lastly, this scheme may never have been used for "on-axis" injection, which may be important during the commissioning of the storage ring, or troubleshooting. Therefore, we are considering including a separate pulsed kicker just before the PSM to accomplish this mode of injection when required.

CONCLUSIONS

We are considering several injection schemes for the NSLS-II's injection straight section, with the intent of increasing the reliability of the injector. Another important goal of this analysis is in moderating tolerances for the pulsed magnets, so to minimize the transients they induce on the stored beam, and, thus, make the injection process transparent for NSLS-II users.

The PSM scheme is a promising solution to designing the injection straight section. The PSM's main advantage is in simplifying the design of the injection straight and reducing number of the pulsed magnets. However, the PSM scheme requires tight arrangement of the injection straight section and a complex modification of the transport line optics due to strong focusing of the injected beam passing off the PSM axis. In addition, small injection transient of stored beam orbit severely constrain tolerance on the vertical alignment of the magnet.

We will analyze feasibility of the PSM scheme by detailed design of the injection straight section. In the next year we are planning to develop and test a PSM prototype.

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