INJECTION STRAIGHT PULSED MAGNET ERROR TOLERANCE STUDY FOR TOP-OFF INJECTION*

G.M. Wang[#], T. Shaftan, R. Fliller, B. Parker, R. Heese, S. Kowalski, F.J. Willeke, Photon Sciences, BNL, Upton, NY, 11973, U.S.A

Abstract

NSLS II is designed to work in top-off injection mode. The injection straight includes a septum and four fast kicker magnets. The pulsed magnet errors will excite a betatron oscillation. This paper gives the formulas of each error contribution to the oscillation amplitude at various source points in the ring. These are compared with simulation results. Based on the simple formulas, we can specify the error tolerances on the pulsed magnets with the goal to minimize the injection transient and scale it to similar machines.

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 per minute) during which the stored beam orbit is highly desired as transparent. But the errors, from the SR pulsed magnets at the injection straight – kickers (non-closed injection bump) and pulsed septum (time-dependent stray field), excite a stored beam betatron oscillation. The magnitude of the perturbation can be large disturning some of the user experiments. In 2010 injection straight review, based on the experts' experiences in ALS [2], DIAMOND [3], SLS [4] and SPEAR [5], we came to the conclusion that the acceptable oscillation amplitude at the long straight is set as 100 μm (i.e. 0.7 σx) in horizontal plane and 12 μm, 2.5 σy, in vertical plane for NSLS II.

This paper gives the analysis estimate of the different error source tolerance from the pulse magnets and scales it to our requirements. The result is compared with simulation.

INJECTION STRAIGHT LINE

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, as shown in figure 1.

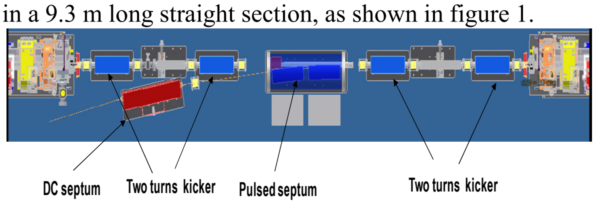

Figure 1: The injection straight line layout.

The four kicker magnets, K1 to K4, are placed symmetrically in the straight section. Their bending angles are the same, but different bend direction. There are only drift spaces between kickers, so the closed bump does not depend on the machine optics. The waveform is half sine with 5.2 μs pulse length, which is two times of storage ring revolution, so every stored bunch goes through the closed bump twice for each injection. The stored beam bump amplitude is 15 mm. When the injected beam arrives, kickers K1 and K2 kick the stored beam towards the septum knife by 15 mm. At the exit of the septum, the stored beam and the injected beam will be separated by 9.5 mm. 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 9.5 mm off-axis. The designed parameters for the pulse magnets are listed in Table 1.

Table 1: Storage Ring Injection Pulse Magnets

Parameter	Kicker	Pulsed septum	Unit
Maximum Field	131	850	mT
Magnet effective Length	650	1300	mm
Maximum Bend Angle	7.85	100	mrad
Magnet Aperture X*Y	90x41	24 x10	mm
Pulse Shape	Half Sine	Full sine	
Pulse Length	5.2	200	μs
Peak Current*	4.7	7.41	kA
Magnet inductance	2.2	4.1	μH

STORED BEAM OSCILLATION WITH DIFFERENT ERROR

Oscillation Sources

During each injection, the stored beam oscillation could come from septum field leakage error, kicker field uniformity error, amplitude error, timing error, and alignment error. The kicker field uniformity error and alignment error is repeatable and can be corrected. The kicker amplitude error and timing error is time dependent.

Oscillation Coupling

The betatron oscillation could be written as

$$x = \sqrt{2J_x\beta_x}cos(\bar{\varphi} + 2\pi\nu + \phi_0) \quad (1)$$

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#gwang@bnl.gov

The betatron oscillation amplitude reflects the maximum deviation, which depends on the beta function

(2)

It is similar for y plane with oscillation amplitude as

(3)

where J is a constant, depending on the initial condition, β is the beta function along the ring.

Due to the error in storage ring, the oscillation in x plane will be coupled to y plane. It is similar to the emittance coupling.

(4)

By combining the above equations, we get the conclusion that at one source point, the ratio of horizontal oscillation to beam size will induce the same ratio of vertical oscillation to the beam size.

(5)

We can also get the relation that the oscillation amplitude ratio of positon to angle is equal to the ratio of the beam size to beam divergence.

(6)

So, positon oscillation amplitude and angle oscillation amplitude are equivalent as the scale to limit the betatron oscillation.

Error Propagation

Ideally, the kicker waveform is

( ) (7)

Where is the designed maxmium kick angle, and is store ring revolution. So in the first turn, the beam gets one kick as and in the second turn, it gets the second kick as .

At the middle of injection straight line, the four kickers' field amplitude error effect on the x plane, is

(8)

Considering the worst case, the kick angle error amplitude is

(9)

Where is the rms value of the amplitude error. Here, we use the approximation that the beta functions at the kickers are the same as the middle point. The betatron oscillation amplitude at the source due to the field amplitude error is

(10)

Where the beta function is at the injection straight line middle point and is at the source point.

The field uniform error propagation has the same property as the amplitude error. So we'll use the same conclusion.

Similarly, at the middle of injection straight line, the kick angle error from the kickers' timing error effect on the x plane, is

(11)

Field amplitude error, field uniform error and timing error affect the beam oscillation in x plane and this oscillation will be coupled to y plane.

As the alignment error, we only consider the tilt error effect on y plane. With the designed beta function and phase advance in y plane, the kick angle error amplitude is

(12)

The septum waveform is a full sine with 200 μs pulse length, but its leakage field to the storage ring rises up and decays slowly, lasting much longer, ~ms. Figure 2 shows an Opera [6] simulation result. The peak value was chosen for estimation. The kick angle error amplitude is

(13)

Where is the leakage field integral and is the stored beam momentum rigidity.

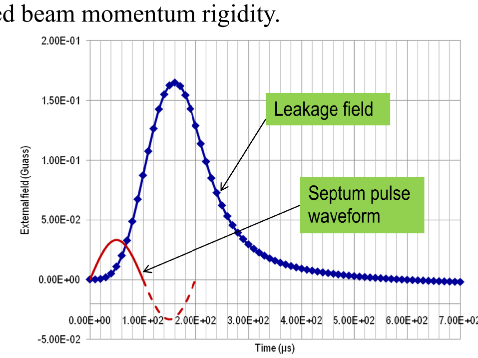

Figure 2 : Pulsed septum leakage field in storage ring.

Table 2: Pulsed Magnet Error Tolerance

Magnet name	Error	value
kicker	Field uniformity	>0.014%
	Amplitude error	1.02 μrad
	Timing error	225 ps
	Tilt error	337 μrad
Pulsed septum	Leakage field integral	35 μT-m

We evenly distribute each error contribution to the betatron oscillation. For x plane, 100 μm in x plane corresponds to . So the maxmium kick angle error is at the middle of the injection straight line. For the y plane, the maxmium kick angle error is , from the error coupling and the tilt error.

Applying the above scale law, the tolerated pulse magnets errors are summarized in Table 2.

ELEGANT SIMULATION

Elegant [7] is used to simulate the pulsed magnet error effects on the stored beam. The input lattice file has a set of random error with orbit correction. Tracking takes into account the synchrotron radiation and turns on the RF system. The beam parameters at the source point of storage ring are shown in Table 3.

Table 3: Beam Parameters at the Source Point

	Source point	Parameter	Value	Unit
X plane		εx	0.86	nm-rad
	Short Straight	σx	40.3	µm
		σxp	21.3	µrad
	Long Straight	σx	128	µm
		σxp	6.69	µrad
Y plane		εy	0.008	nm-rad
	Short Straight	σy	2.97	µm
		σyp	3.29	µrad
	Long Straight	σy	5.35	µm
		σyp	1.92	µrad

Each bunch is represented by a macro particle, separated by 2 ns. The kicker magnets and pulsed septum leakage field are simulated with the bumper element, and the waveform is implemented from an input file. The simulation uses the errors listed in table 2, tracking 1400 turns (longer than the septum leakage field time).

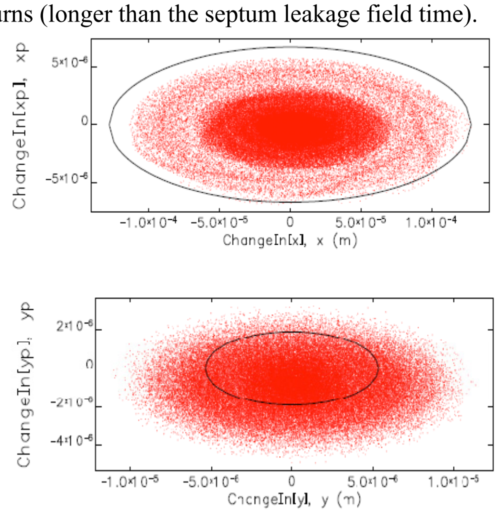

Figure 3: The beam transverse position and angle oscillation at the injection straight line

At the injection straight, figure 3 shows the stored beam position and angle oscillation in different turns. The black line shows the contour of the rms beam size and divergence. The red is the beam center at different turns. For x plane, the maximum position oscillation is ~100 µm. And in y plane, the maximum position oscillation is ~12 µm. It agrees with our scales.

SUMMARY

For top off injection, the stored beam center oscillation due to kicker errors and septum leakage field will be visible to the user. Each error effect on the stored beam has been analyzed and agrees well with the simulation.

The analysis result can quickly be applied to specify each error tolerance at the pulse magnets. For the tight requirements on timing error, limited by x plane oscillation, we may correct the kicker field uniformity error by introducing an matched waveform with µrad amplitude, which locates at 180*n degree phase advance relative to the injection straight line. The tilt error effect on y plane can be corrected in the similar way.

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