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ALTERNATIVE INJECTION SCHEMES TO THE NSLS-II USING NONLINEAR INJECTION MAGNETS*

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Abstract

The NSLS-II storage ring uses the standard four bump injection scheme to inject beam off axis. BESSY and MAX-IV are now using a pulsed multipole magnet as an injection kicker. The injected beam sees a field off axis for injection while the stored beam experiences no field on the magnet axis. The principle advantage of using a pulsed multipole for injection is that the stored beam motion is greatly reduced since the field on axis is negligible. The number of pulsed magnets is reduced from five in the nominal scheme (septum and four bumps) to two or three thereby reducing the possible failure modes. This also eliminates the need to precisely match the pulse shapes of four dipole magnets to achieve minimal stored beam motion outside of the bump. In this paper we discuss two schemes of injecting into the NSLS-II using a pulsed multipole magnet. The first scheme uses a single pulsed multipole located in one cell downstream of the injection septum as the injection kicker. The second scheme uses two pulsed multipoles in the injection straight to perform the injection. We discuss both methods of injection and compare each method.

INTRODUCTION

The NSLS-II storage ring injection system uses a standard four bump injection scheme to inject beam off axis. Though this is a proven and well-established design for injection into a light source ring, it suffers from several drawbacks. Space is required for the four kickers. Closing of the bump is generally only possible for the maximum amplitude of the bump. Mismatches on the pulses and the chamber coats make matching the fields at all amplitudes difficult. Another reason may be that the bump passes through sextupoles which provide an amplitude dependant kick. This stored beam motion is not desirable to users, particularly imaging beamlines or those with samples sensitive to damage.

Reliability of the pulsers is an issue since there are multiple pulsers that may fail. This would stop the injection process, and likely kick the stored beam from the machine. Depending upon the design of the pulser, this may require access into the storage ring tunnel for repair. Therefore a method of injection that can solve these issues would be beneficial to light source operation.

Several light sources are pioneering a pulsed multiple for injection to resolve these issues [1, 2]. The idea is that the injected beam would experience the necessary field while the stored beam would see no field. BESSY II and MAX-IV have pioneered the use of a nonlinear kicker for injection [3]. This kicker is not a pure multipole and allows for the possibility of zero or reduced gradient at the injected beam location as well as for zero field and gradient at the center of the magnet for the stored beam.

In this paper we discuss two schemes for using nonlinear kicker magnets for injection into the NSLS-II storage ring. The first scheme uses a single kicker magnet for injection, and the second scheme uses two such magnets. We compare and contrast the two methods. We also discuss heating concerns for the ceramic chambers.

SINGLE KICKER INJECTION

The nonlinear kicker used is based on the BESSY II and MAX-IV design. In this design, eight wires are placed in an X pattern about the center with two wires on each leg of the X are radii R_1 and R_2. All of the wires carry the same current with the outer wires having opposite sign. This give zero field and gradient in the center and a field maximum on the horizontal and vertical axis at $R_1<R<R_2$, as shown in Fig. 1 [3].

It is possible that the inner and outer wires do not necessarily form a single X while maintaining the necessary field parameters. This allows some additional freedom for increasing the vertical aperture as well as other optimizations.

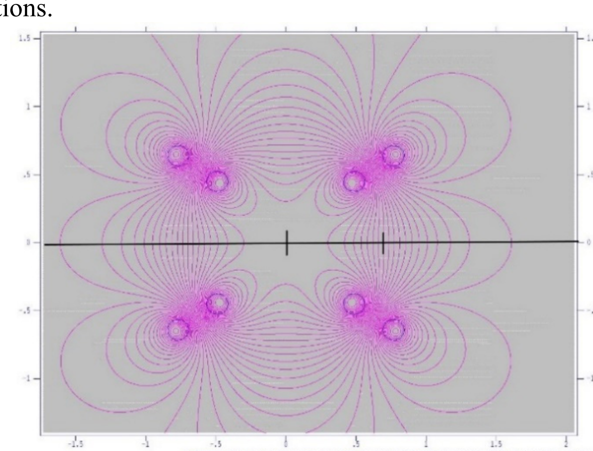

Figure 1: Field Map of the Nonlinear Kicker. The vertical lines show the zero field and maximum field locations on the horizontal axis.

Table 1 lists the relevant parameters of the injection kicker magnet. The field maximum location was chosen to that this same magnet could be used in both scenarios and

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still provide enough aperture for injection and reduce chamber heating as much as possible.

Table 1: Parameters of Nonlinear Kicker

Parameter	Value
R_1	6.6 mm
R_2	10.4 mm
Length	300 mm
I	2344 A
Field Maximum Location	-7.0 mm
Field Maximum	-111 mT
Injection Point	-5.4 mm
Required Kick Angle	2.83 mrad
Field at Injection Point	-89 mT
Gradient at Injection Point	-262 mT/m
Inductance	984 nH
Pulse Shape	Half sine
Pulse Length	5.28 µs
Voltage	2.7 kV

Figure 2 shows a preliminary design of the vacuum chamber of this magnet. The chamber is ceramic with an inner aperture of the chamber is a racetrack shape with a 4.5 mm radius circular relief in the center for the stored beam. Two water cooling channels are provided to remove the heat induced by the beam.

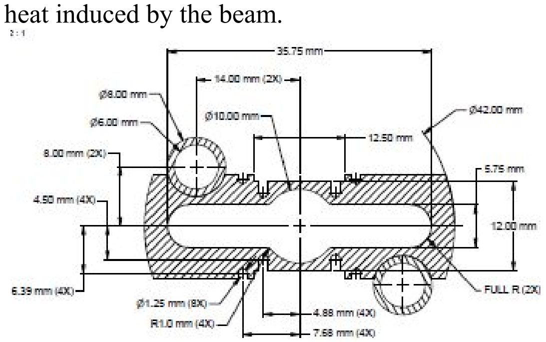

Figure 2: Preliminary design of the vacuum chamber.

Figure 3 shows the injected beam trajectory through the storage ring from the septum through the first cell to the nonlinear kicker located at the end of the straight section. This location was chosen as the closest location a magnet of this type could be placed and kick the injected beam into the storage ring acceptance. The beam location is not at the field maximum of the magnet. As stated above it is not desired the close the aperture any more to move the field maximum in. It is obvious from the figure that moving the beam out to the field maximum is not possible because of the physical aperture, nevertheless it would not be possible to kick the beam into the ring acceptance at that amplitude.

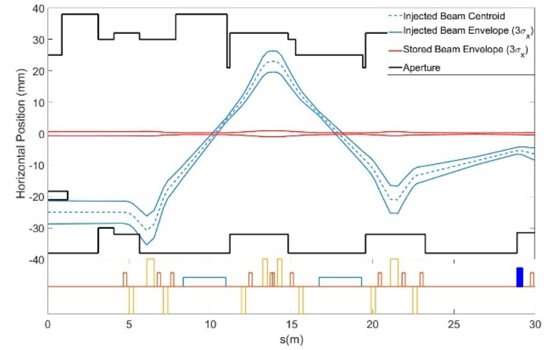

Figure 3: Trajectory of the injected beam from the septum to the nonlinear kicker.

Figure 4 shows simulations of the injected beam at injection and the first seven turns at the septum. All of the injected beam makes it beyond the septum. The large smearing of the beam on the first turn is because of the gradient that the beam sees at the nonlinear kicker.

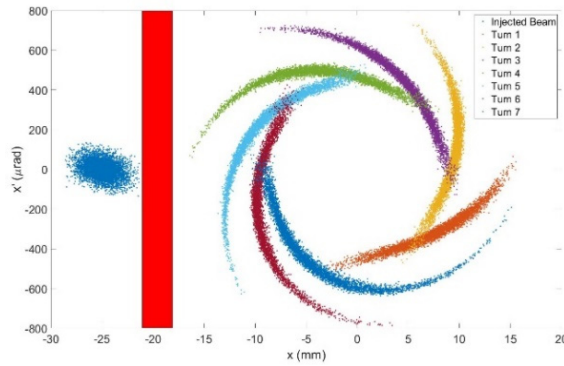

Figure 4: Injected beam position at the injection septum.

Stored beam motion from the kicker was simulated by misaligning the nonlinear kicker. The motion tolerance was set to 1/10 of the beam size at the source points. This gives a maximum misalignment of 400 µm x150 µm of the kicker to achieve this motion. Injection is still successful with these misalignments.

There are several concerns with this arraignment. The first is that the match of the incoming transport line is difficult. The horizontal beta function at the kicker location is limited by the septum aperture and therefore optimal matching at the kicker is not possible. This means that the injected beam will require more dynamic aperture. The injected beam passes through extremes of the magnets and near the physical aperture as it passes from the septum to the kicker. For successful injection, the beam should arrive at the kicker with the proper trajectory. Therefore a number of beam studies have been proposed to ensure that injection can be successful.

One advantage of this method not stated thus far is that is leaves the standard injection magnets untouched. They reside in the ring as a backup system that can be brought to bear if the nonlinear kicker should fail [4].

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DUAL KICKER INJECTION

In a standard four bump injection scheme, the four bump magnets move the stored beam close to the septum to place the injected beam close it. The injected beam follows the stored beam through the third and fourth bumps. One can use two nonlinear kickers to make an identical injection trajectory while minimizing the stored beam disturbance [5].

Injection with two nonlinear kickers proceeds as follows. The four bumps are not used, and the stored beam is not bumped. The third and fourth bump magnets, those after the septum, are replaced with two nonlinear kickers. These kickers would have their field maximum at the location of the injected beam during the four bump injection. In this way, the fields experienced by the injected beam are identical to the usual injection process. The stored beam sees no field.

The two kicker magnets are necessarily different because the field maxima are at different locations in each kicker. For NSLS-II the injected beam enters the vacuum chamber 22.6 mm from the central orbit. A large aperture nonlinear kicker is designed to have its field maximum at this location. The parameters of this magnet are listed in Table 2. Figure 5 shows the field.

Table 2: Parameters of Nonlinear Kicker for Two Kicker Injection Scheme

Parameter	Value
R_1	21.6 mm
R_2	30.3 mm
Length	300 mm
I	8965 A
Field Maximum	-23.0 mm
Injection Point	-22.6 mm
Required Kick Angle	7.54 mrad
Field at Injection Point	257 mT
Gradient at Injection Point	0 mT/m
Inductance	1.7 µH
Pulse Shape	Half sine
Pulse Length	5.28 µs
Voltage	18.0 kV

The second magnet is located 2 m downstream of the first. The injected beam is located 7 mm from the center and the magnet in the previous section can be used with only a factor of 2.3 increase in the current and drive voltage.

We studied the effect of the two nonlinear kickers on the stored beam. We simulated the stored beam motion for various combination of combined displacements of both kickers. Offsets of 200 µm x 50 µm were adequate in most cases. Though the tolerances are tighter than in the single kicker injection case, they are achievable in practice.

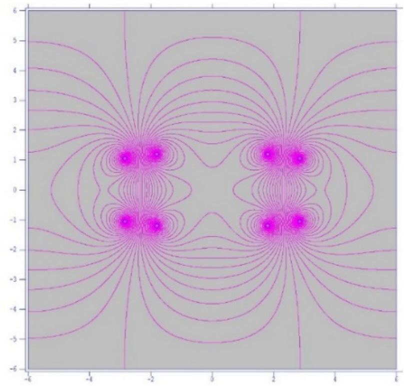

Figure 5: Field Map of the Large Aperture Nonlinear Kicker required for two kicker injection.

CHAMBER HEATING

Heating of the vacuum chamber is relevant for any synchrotron light source. NSLS-II has already seen the detrimental effects of heating of ceramic chambers [6]. The small aperture of the nonlinear kicker magnet amplifies these concerns. So it is of paramount important to understand how the beam may heat the chamber as this may lead to a beam current limitation as it has in MAX-IV [7].

The present plan is to coat the ceramic chamber with a 5 µm Ti coating. TOSCA simulations show that coating attenuates the magnetic field <0.2%. Heating of the ceramic chamber from the beam is determined via the calculation of the power loss $P_{loss} = T_0 {I_0}^2 k_{loss}/M$, where $k_{loss} = \frac{1}{\pi}\int_0^\infty d\omega\ \mathrm{Re}Z_0^{||}(\omega)e^{-\sigma_t{}^2\omega^2}$. The longitudinal impedance $Z_0^{||}$ is calculated with the standard field matching technique [8], via modelling the metallic coating and ceramic chamber boundaries as parallel plates. The parameters for the power loss and impedance calculation are listed in Table 3.

Table 3: Parameters for Power Loss Calculation

Parameter	Symbol	Value
Revolution period	T_0	2.6 μs
Average current	I_0	0.5 A
Number of bunches	M	1000
Bunch length	σ_t	20 ps
Ceramic chamber half-aperture	b	5 mm
Ceramic chamber thickness	d	1 mm
Ceramic relative permittivity	ε_r	10
Ti-conductivity	σ_{Ti}	2.6 $\times 10^6$ S/m

The power loss as a function of the Ti-coating thickness τ is shown in Figure 6a) by the red trace. For the planned thickness of 5 µm and bunch length $\sigma_t = 20$ ps, the power loss is 8 W, close to the value of 6.9 W predicted by the thick-wall limit (pure metallic vacuum chamber [9]). This can be understood from the blue trace in Figure 6a), which shows the frequency ω_r at which the skin depth d_s is equal to τ, i.e. $\omega_r = 2/(\mu_o\sigma_{\mathrm{Ti}}\tau^2)$, and the bunch spectrum shown in Figure 6b), where a significant portion of the spectrum is at frequencies higher than $\omega_r(\tau = 5\mu m) =$ 3.9GHz.

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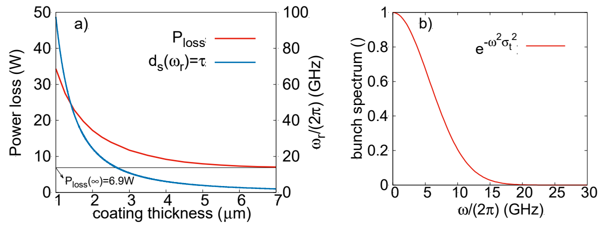

Figure 6: a) power loss P_{loss} and ω_r vs. coating thickness τ, where ω_r is the frequency at which the skin depth d_s is equal to τ. b) bunch spectrum for a bunch length $\sigma_t = 20$ps.

CONCLUSION

We have shown two methods of using nonlinear kicker magnets for injection into the NSLS-II storage ring. The single kicker method requires the injected beam to make large amplitude oscillations through the first cell and has challenges to matching the transport line but keeps the standard four bump injection scheme as a backup system. The dual kicker system requires a large aperture nonlinear kicker with a challenging pulsed power supply but is easily incorporated into the ring. The heating of the ceramic chamber is a major concern. Further work is ongoing to understand how beam will affect the chamber.

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