NSLS-II PULSED MAGNET DESIGN CONSIDERATIONS

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Abstract

Brookhaven National Laboratory (BNL) is developing NSLS-II [1], a state-of-the-art 3 GeV synchrotron light source, the successor to the NSLS. Pulsed magnets are required for injection/extraction into the ring and into and out of the 200 MeV to 3 GeV booster synchrotron. Top-off mode of operation requires demanding stability, synchronization and field quality of the pulsed magnets of the synchrotron due to the very low emittance of the ring and the tolerances for maximum beam motion asked for by the users who may not be able to deal with blanking of data acquisition due to an injection transient and damping cycle[2]. We describe here the approach taken for the design of the booster injection and extraction pulsed magnets and the pulsed magnets for the two modes of injection being considered for the storage ring injection system.

BOOSTER INJECTION/EXTRACTION

The injection into the booster takes place in one of its 8.62 meter-long straight sections and consists of a septum and a single full aperture kicker to place the pulse train from the 200 MeV linac directly on the closed orbit of the booster.

The layout of the booster injection straight section is shown in Figure 1(A), and the magnet parameters are set out in Table 1 below. Keep in mind that the injection takes place at an energy of 200 MeV; the alignment, field and survey tolerances are not difficult to meet and should present no problems for this conventional injection system.

There is some uncertainty whether the linac will be able to produce 15 nanocoulombs per pulse train for a single shot injection process into the booster. As a backup for this eventuality, a four bump injection scheme has been developed for the booster, which will be able to accept and store two consecutive pulse trains from the linac before acceleration begins. It takes advantage of the 0.64 fractional tune value of the booster, is quite feasible but will require a re-design of the linac-to-booster transport line. It will not be discussed further

Table 1: Pulsed magnet parameters for booster injection scheme

Parameter	Pulsed septum	Kicker
Length, m	0.75	0.2
Field, T	0.127	0.025
Angle, mrad	142.5	7.5
Aperture x/y, mm	20/15	67/27
Pulse shape	Full sine 100 µs	300 nsec FT, <200 nsec fall time
Flatness/ Field Error tolerance, %	n/a/0.03	0.2/0.2
Align.tol., roll (mrad)	100/100/0.2	100/100 /0.2

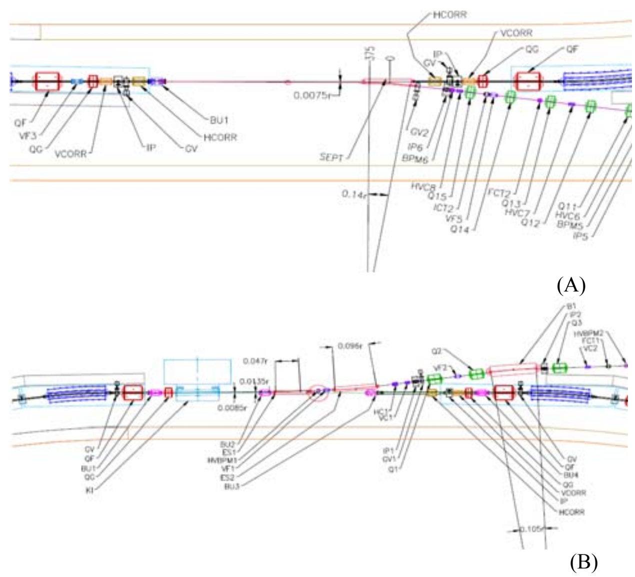

Figure 1: Booster layout for (A) injection straight, and (B) extraction straight.

Table 2: Pulsed magnet parameters for booster extraction scheme

Parameter	DC septum	Pulsed septum	Extrac Kicker	Orbit Bump
Length, m	1	0.6	1.0	0.2
Field, T	1.009	0.8	0.05	0.375
Angle, mrad	96	48	5	7.5
Aperture x/y, mm	50/20	20/15	67/27	67/27
Pulse shape/width (FT)	n/a	1/2sine 100 µs	200nsec risetime (300ns)	½sine 1000 µs
Flatness/ Field Error tolerance, %	n/a/ 0.03	0.2/0.2	8E-3 ripple & droop	n/a/ 0.01
Align. tolerances, roll (mrad)	100/100 /0.2	100/100 /0.2	100/ 100/ 0.2	100/ 100/ 0.2

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The layout of the booster extraction straight is shown in Figure 1(B) and extraction magnet parameters are shown in Table 2.

Four closed slow orbit bumps move the booster beam toward the extraction septum; the extraction kicker situated between bump 1 and 2 then kicks beam across the septum into the extraction channel. The extraction septum is broken up into two pieces – a pulsed septum as short as possible followed by a DC extraction magnet to clear the downstream booster hardware. The fringing field from the DC magnet is kept out of the booster beam chamber by ferrous shielding, judicious design keeps the stray field below 0.5 gauss at the magnet's closest point.

The magnetic field pulse of the extraction kicker determines the horizontal stability of the pulse train extracted from the booster. Any ripple or droop of the flat-top will produce horizontal positional variation within the extracted bunch train and will thus add to the effective emittance of the beam. This is especially important for the pulsed sextupole injection option discussed below [3].

These tight tolerances will be addressed with prototype magnets and drivers in the NSLS-II pulsed Magnet Lab.

RING INJECTION - 4-KICKER BUMP VERSUS PULSED SEXTUPOLE

. The NSLS-II's storage ring features long straight sections (9.3 m between the yokes of the outer magnets), adequate for both types of injection methods.

The four-kicker orbit bump is a conventional injection scheme used in many labs. We split the injection septum into two parts, DC and pulsed, to minimize the strength of the pulsed magnet to ease its design and moderate its tolerances. Our baseline design calls for weak kickers to correct non-closure of the orbit bump. The pulsed magnet parameters are listed in the table below:

Table 3: Pulsed magnet parameters for the 4-kicker bump injection scheme

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	Full sin 100	½ sine 5.2	½ sine 5.2
Flatness/ Field Error tol. %	n/a/ 0.03	0.2/0.2	8E-2	0.01
Align. tol, µm/µm/mrad	100/100 /0.2	100/100 /0.2	100/100 0.012	100/10 0/0.2
Inductance, µH	n/a	3.35	1.4	0.5
I, kA/V,kV		5.5/1.16	4.2/3.7	1.4/.45

In a paper at these proceedings [4], the analysis of pulsed magnet tolerances is presented, and the results were similar to those obtained at the SLS [5]. It was shown that roll around the longitudinal axis of the kicker, which gives rise to unwanted vertical kicks was the most stringent parameter, requiring field alignment deviation from the vertical of less than about 12 µradians. This tolerance will be very difficult to attain and maintain. For this reason we are planning to install horizontal field cancelling coils in each kicker capable of drawing a small part (~1 A max.) of the main current pulse to counteract any errors in alignment, similar, but not exactly like the H_t windings [6]. Final set-up of these windings will be done after measurement and survey in the ring with circulating beam during commissioning. Exact configuration of these coils will be determined on kicker prototypes in the NSLS-II Pulsed Magnet Lab.

Figure 2 below shows the difference in lay-out between the four bump scheme and the pulsed sextupole magnet (PSM) injection discussed below:

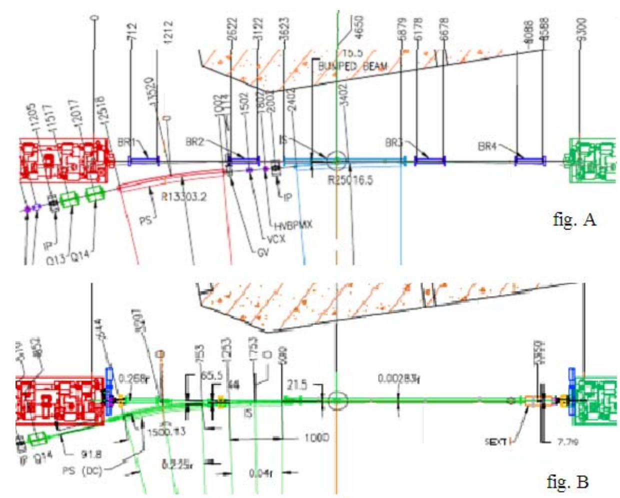

Figure 2: Storage ring layouts for (a) the 4-kicker scheme, and (b) the PSM scheme.

The PSM injection scheme has the clear advantage in reducing the number of pulsed magnets and elimination of

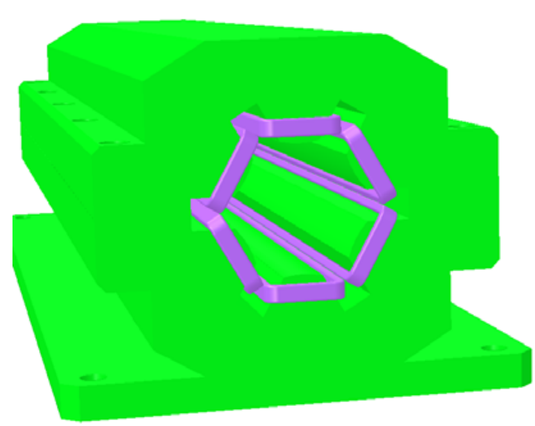

Figure 3: View of pulsed sextupole magnet configuration.

the need of bumping the stored beam during top-off injection, but as indicated in [4], the alignment and positioning of the PSM is very critical to keep the source point for the users stable to 10% of the beam size. This leads to a 10 µm tolerance of vertical positioning

Table 4: Pulsed magnet parameters for the PSM injection scheme

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	$10^2/10^2/0.2$	$10^2/10^2/0.2$	100/10/1
Inductance µH	n/a	3.35	14
I(ka)/V(kV)	n/a	5.25/0.56	3.2/27

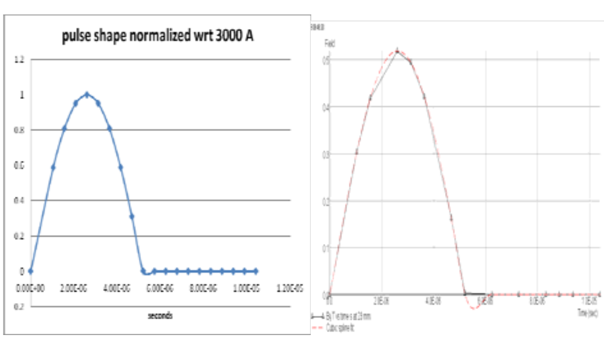

Figure 4: Current applied and resulting B_y of PSM.

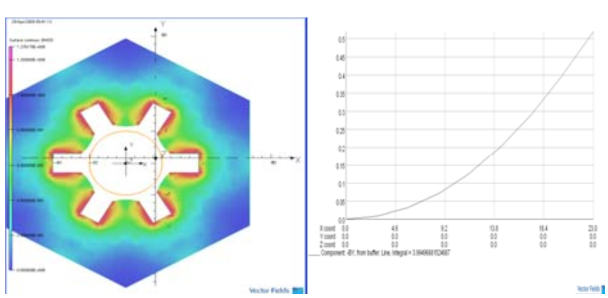

Figure 5: Saturation of simulated very preliminary PSM lamination and B_y (T) as function of radius from axis of PSM in mm.

The PSM will be constructed of ¼ mm laminations and the final magnet pole shape will be precision EDM-wire cut after assembly to accurately conform to the calculated mechanical requirements and ensure the straightness of the bore. Furthermore, the magnet will be mounted on a micro-positioning table in the ring to allow beam-based alignment capability.

To inject into the ring for commissioning without use of the PSM, a small on-orbit kicker (20 cm long, 3.5 mR) is planned upstream of the PSM to inject a single pulse train from the booster.

We are building a PSM prototype to study how to meet these tolerances, and optimization of the parameters are still in progress in order to attempt to relax them.

A SINGLE PULSED MAGNET INJECTION

Fringing fields from the septum can form a large part of disturbance to the beam during top-off mode. Careful design, use of eddy current shields and full sine wave excitation can reduce these to minimum, but it would be attractive to do away with the pulsed septum and use a Lambertson septum. We are currently analyzing the feasibility of this concept.

CONCLUSIONS

The injection and extraction schemes for the booster are relatively straightforward. The stringent requirements for the kicker magnets are the rise and fall times of 200 nsec or less with minimum ripple and droop of the 300 nsec flat-top. Careful driver design is imperative for these devices. If the linac charge of >15 nanocoulombs cannot be easily maintained, a four kicker injection bump scheme is under consideration to allow the injection of two successive linac bunch trains into the booster. We are considering three schemes for the NSLS-II's injection straight section, with the intent of decreasing the impact of any injection transient on the stored beam. The reduction of the number of pulsed elements also means an increase in the reliability of the injection system. The main goal of this process is to minimize the transients induced on the stored beam, and to make the injection process transparent for NSLS-II users.

ACKNOWLEDGEMENTS

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