BEAM STACKING IN THE NSLS-II BOOSTER*

R. P. Fliller III#, R. Heese, S. Kowalski, J. Rose, T. Shaftan, G. Wang,
NSLS-II Project, Brookhaven National Laboratory, Upton, NY 11973, U.S.A.

Abstract

The National Synchrotron Light Source II (NSLS-II) is a state of the art 3 GeV third generation light source currently under construction at Brookhaven National Laboratory. The NSLS-II injection system consists of a 200 MeV linac and a 3 GeV booster synchrotron. The linac needs to deliver 15 nC in 80 - 150 bunches to the booster every minute to achieve current stability goals in the storage ring. This is a very stringent requirement that has not been demonstrated at an operating light source. To alleviate the charge requirement on the linac, we have designed a scheme to stack two bunch trains in the booster. In this paper we discuss this stacking scheme. The relevant aspects of the booster lattice are discussed along with the design of the injection straight. We discuss the effects of injection errors on the beam emittance and limits on the linac emittance to permit stacking.

INTRODUCTION

The NSLS-II is a state of the art 3 GeV synchrotron light source under construction at Brookhaven National Laboratory. The NSLS-II storage ring is designed to store 500 mA with a 3 hour lifetime. The users require the current to be stable to 1% and a bunch to bunch charge variation of 20%. To achieve this goal the injection system must deliver 7.3 nC in 80-150 bunches every minute. [1] This places very stringent requirements on the injection system.

The NSLS-II linac is specified to produce 15 nC in 80-150 bunches. This charge and bunch pattern have not been demonstrated at an existing light source. Existing facilities are capable of producing approximately one half of this charge per linac pulse.[2] We have developed a scheme to transversely stack two bunch trains in the NSLS-II booster to ensure that the charge requirement can be met.

In this paper we discuss the scheme to stack two bunch trains in the NSLS-II booster. The relevant aspects of the booster lattice are discussed. This is followed by a description of the booster injection straight and the stacking process. Finally we discuss emittance dilution effects in the injection process and how they will affect stacking.

BOOSTER LATTICE

The NSLS-II injection system has been described in numerous publications.[1] In brief it will consist of a 200 MeV linac and a 3 GeV booster synchrotron. The linac is capable of operating at 10 Hz and is specified to provide an emittance of $4\sigma_x\sigma_{x'}$=155 nm with a 0.5% energy spread.

The NSLS-II Booster is a 158.4 m circumference synchrotron utilizing combined function magnets. The booster is designed to have a 39 nm equilibrium emittance at 3 GeV to meet the injection requirements for the storage ring. The twiss functions for one quadrant are shown in Figure 1.

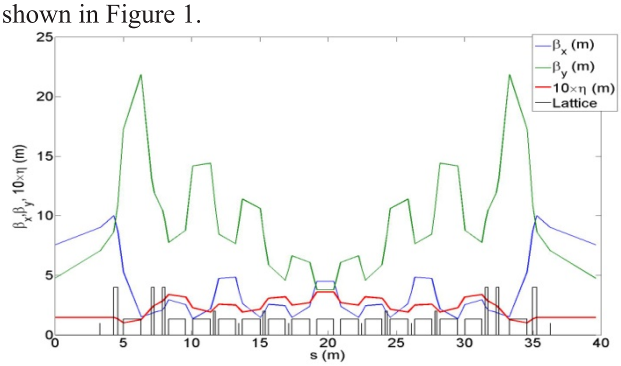

Figure 1: β and dispersion functions through one quadrant of the NSLS-II Booster Reference design.

The anticipated booster aperture is an ellipse with major and minor axes of 20x12 mm^2 in the dipoles. This is chosen to keep the dipole gap small. These apertures place a limit on the machine acceptance, which ultimately limits the number of trains that can be stacked in the booster. Using the twiss functions in Figure 1, one can calculate the available phase space for injection at the end of the injection straight. We call this the stay clear aperture. This is shown in Figure 2. The stay clear aperture area is 31 mm-mrad in the horizontal plane, and 3.6 mm-mrad in the vertical plane. The acceptance limitations come from the large β functions in the quadrupoles at the end of the straight sections.

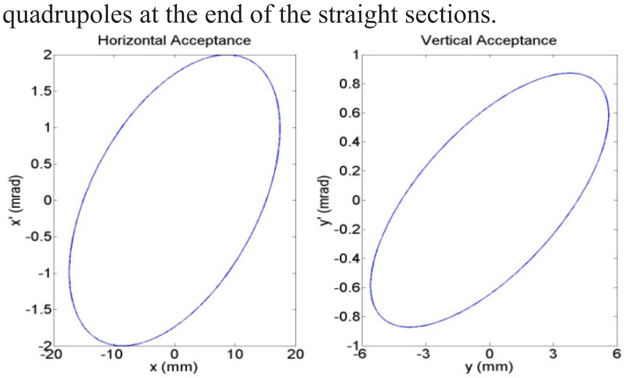

Figure 2: Horizontal and vertical stay clear aperture of the booster reference design.

* This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy.
#rfliller@bnl.gov

The dynamic aperture of the booster was also evaluated.[3] Figure 3 shows the dynamic aperture of the booster at the end of the injection straight. The dynamic aperture is larger than the physical aperture and the stay clear aperture and will not be a limiting factor for beam stacking.

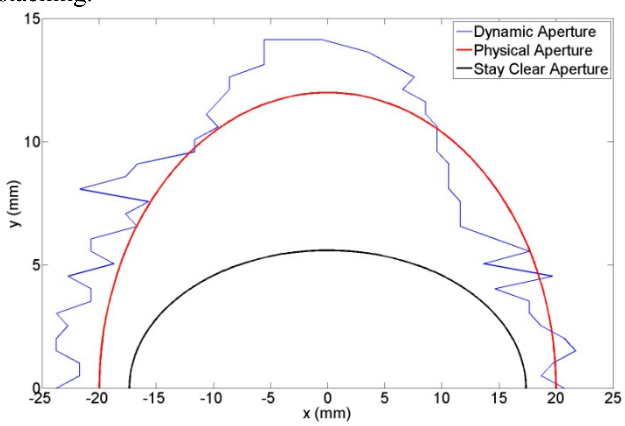

Figure 3: Booster dynamic aperture shown with physical aperture and stay clear aperture.

BOOSTER INJECTION SYSTEM

The current booster injection straight section design is shown in Figures 4 and 5. The straight contains four fast bump magnets, and a pulsed septum magnet between the pairs. The bumps are 20 cm long, capable of kicking the beam 15 mrad, and are separated by 2.25 m to translate the beam 28 mm horizontally. The injection septum is 75 cm long, and kicks the beam 125 mrad. The knife edge is located 20 mm from the central orbit. Table I shows the parameters for the pulsed magnets.

The injection sequence for the first linac bunch train is as follows. When the beam arrives from the linac, it will be 27 mm from the central orbit with no angle. Bumps BR-BU3SI and BR-BU4SI kick the beam 12 mrad each to place the beam on the central orbit with no angle. This is shown in Figure 4. If only one bunch train is desired, the booster can then initiate a ramp.

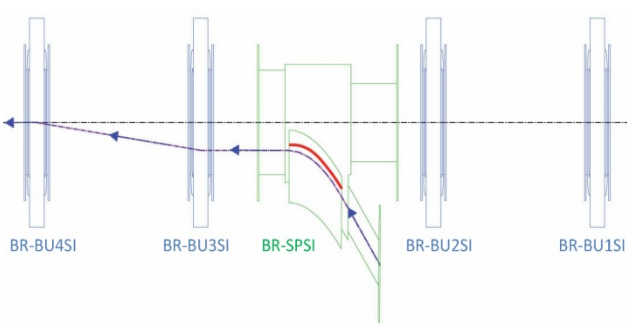

Figure 4: Injection of one bunch train into the NSLS-II Booster.

If a second train is desired, the beam will circulate on the injection porch for 100 ms until the next beam from the linac arrives. Bumps BR-BU1SI and BR-BU2SI will kick the circulating beam with an angle of 7.1 mrad to move it over 17 mm toward the septum. The septum fires normally, placing the second train parallel to circulating train. The beam separation is 10.5 mm center Bumps BR-BU3SI and BR-BU4SI fire with an angle of 9.56 mrad each to place the centroid of the two beams on the central orbit with no angle. At the end of the injection straight the two trains are offset from the central orbit by ±5.25 mm. This process is shown in Figure 5. We note that this is not a closed bump for the circulating beam. A closed bump would require more phase space since the second train would oscillate about the first.

The booster ramp will then start, and the bunches will coalesce through filamentation and radiation damping.

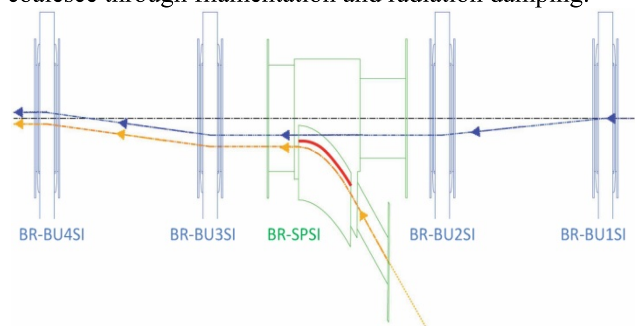

Figure 5: Injection of the second bunch train into the NSLS-II Booster.

Table 1: Parameters of the booster injection pulsed magnets.

Parameter	Septum	Kicker
Bend Angle (mrad)	125	15
Length (cm)	75	20
Aperture (mm^2)	20x15	70x44
Maximum Field (T)	0.110	0.05
Inductance (μH)	1.3	0.4
Peak Current (kA)	1.8	1.9
Drive Voltage (kV)	0.175	15
Pulse Shape	100 μs Full Sine	100 ns Rise, 300 ns Flat Top, 100 ns Fall

STACKING

The performance of the stacking system will ultimately be determined by the phase space area required by the combined beam. The largest factor in this area is the distance between the two beams. If the two beams can be placed close to one another, then less acceptance is required. The minimum spacing of the two beam centers is given by

$$\Delta x = 3\sigma_{x1} + 3\sigma_{x2} + 5\text{mm}$$

where $\sigma_{x1,2}$ are the rms beam size of the first and second beams respectively. The anticipated septum knife is 3 mm and we specify one mm clearance for orbit distortion at the septum for each beam. This is the origin of the 5 mm. Clearly smaller beam sizes allow the beams to be placed closer to each other. This implies that the emittance of each beam, particularly the first injected beam, must be understood and controlled.

At the injection energy of the booster, the transverse damping time is 15 s. The time between bunch trains is 100 ms or 189000 turns, so damping is negligible for the stacking process. This means that any injection errors translate to emittance growth as the first beam circulates and filaments while waiting for the second bunch train.

In particular, errors that cause the injected beam not to lie on the closed orbit are the most troublesome. The largest errors are the ripple in the injection bumps and energy variation along the bunch train due to beam loading in the linac. The bumps are specified to have a ripple less than 2% peak to peak, and the energy slew along the bunch train is assumed to be 0.5%.

First we consider the effect of errors on the injection of the first bunch. This leads to emittance growth of the first bunch. Injection errors on the first beam can increase the emittance by a factor of 3.4.

Simulations were done to determine the effect of circulating in the booster for 100 ms using a beam with 4 times the linac emittance. The bare lattice showed no emittance growth in either plane. Twenty lattices with errors were also simulated. On average, these show no additional emittance growth in the horizontal plane and 11% growth in the vertical plane.

During injection of the second bunch train the ripple on the first two orbit bumps can move the circulating train 17 mm with an error of ±0.67 mm and ±0.23 mrad. The second train position at the injection septum can have an error of ±0.58 mm and ±42 μrad. These combined errors determine the minimum acceptance needed for the combined beam in the booster.

The second two injection bumps can move the combined beam orbit onto the central orbit to within ±0.56 mm and ±0.31 mrad limited by the ripple. Deviations from the closed orbit further increase the acceptance the beam needs.

Figure 6 shows the effects of these errors on the acceptance at the end of the injection straight. The outermost black ellipse is the acceptance of the bare lattice as in Figure 2. The dashed black ellipse is the acceptance which has been reduced by closed orbit distortions. The larger green ellipse is the emittance of the first beam after being blown up by injection errors. The smaller green ellipse is the second beam injected from the linac at the specified emittance. The relative position of the two beam ellipses assumes that all of the errors add up in the most detrimental way with a value equal to twice the rms value. The blue ellipse is the phase space necessary to contain the combined beam. As Figure 5 shows, even after including all injection errors, the booster contains enough acceptance to stack two beams.

Stacking of three beams was briefly considered. If the beams circulate for another 100 ms they would filament and fill the blue ellipse in Figure 6. This would not leave enough phase space to inject a third beam into the booster. This is no longer being considered.

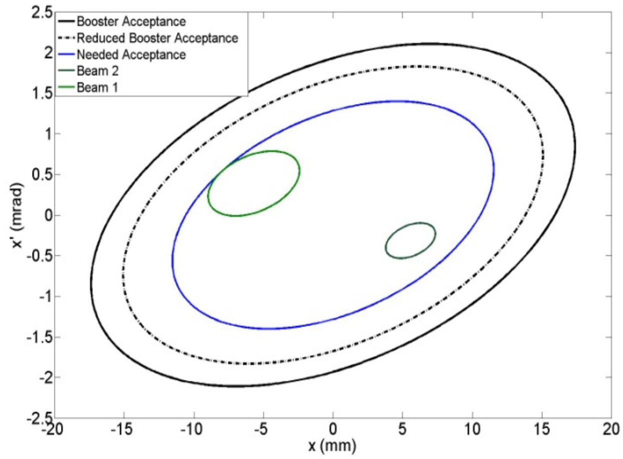

Figure 6: The booster horizontal phase space at the end of the injection straight after the injection of the second bunch train. Sufficient phase space exists for two beams to circulate.

CONCLUSION

The NSLS-II injection system needs to provide bunch trains of 80 to 150 bunches containing 7.3 nC to the storage ring every minute. The linac needs to provide 15 nC to the booster to accomplish this goal. This has not been demonstrated at an existing light source.

We have developed a bunch stacking scheme that will allow us to inject 15 nC into the booster if the linac does not meet its design goal. This scheme utilizes four injection bumps to place two bunch trains in the booster. We have shown that the booster has enough acceptance and dynamic aperture to contain the stacked trains. Calculations of injection tolerances and simulations of the circulating beam show that with the current design the booster has ample acceptance to stack two beams.

Simulations are underway to understand how this large beam is accelerated in the booster.

REFERENCES

[1] T. Shaftan, R. Alforque, Alexei Blednykh, W. Casey, L. Dalesio, M. Ferreira, R. P. Fliller III, G. Ganetis, R. Heese, H.-C. Hseuh, P. Job, E. Johnson, Y. Kawashima, B. Kosciuk, S. Kowalski, S. Krinsky, Y. Li, H. Ma, R. Meier, S. Ozaki, D. Padrazo, B. Parker, I. Pinayev, M. Rehak, J. Rose, S. Sharma, O. Singh, P. Singh, J. Skaritka, C. Spataro, G. Wang, F. Willeke." Status of the NSLS-II Injection System" these Proceeding WEPEA082.

[2] A. Setty, D. Jousse, J-L. Pastre, F. Rodriguez, A. Sacharidis, R. Chaput, J-P. Pollina, B. Pottin, M-A. Tordeux. "Commissioning of the 100 MeV Preinjector Helios for the Soleil Synchrotron." Proceedings of the European Particle Accelerator Conference 2006, Edlinburgh, Scotland. TUPCH112.

[3] T. Shaftan, R. Fliller, R. Heese, J. Skaritka, J. Rose, S. Sharma, G. Ganetis, B. Dalesio, D. Hseuh. 'NSLS-II Booster Design" NSLS-II Technical Note 61.