NSLS-II BOOSTER ACCEPTANCE STUDIES*

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Abstract

The NSLS-II is a state of the art 3 GeV synchrotron light source being developed at BNL. The injection system will consist of a 200 MeV linac and a 3 GeV booster synchrotron. The injection system must supply 7.3 nC every minute to satisfy the top off requirements. A large booster acceptance is necessary to have a high booster injection efficiency and alleviate the requirements on the linac gun. We also anticipate transverse stacking of bunches in the booster to increase the amount of charge that can be delivered. We present studies of the anticipated booster stay clear and the ramifications for injection efficiency and transverse stacking.

INTRODUCTION

The NSLS-II is a state of the art 3 GeV synchrotron light source being developed at BNL. The injection system will consist of a 200 MeV linac and a 3 GeV booster synchrotron. The injection system must supply 7.3 nC every minute to satisfy the top off requirements. A large booster acceptance is necessary to have a high booster injection efficiency and alleviate the requirements on linac gun. We are also considering the possibility to transversely stack bunches in the booster. This will reduce the charge requirements on the linac gun and allow us to inject more change into the storage ring.

In this paper we discuss acceptance studies of the CD-2 version of the NSLS-II booster lattice. The implications of the booster acceptance on injection and transverse stacking are also discussed.

NSLS-II INJECTION SYSTEM

The design of the NSLS-II injection system has been described in previous publications.[1][2] In brief, it consists of a 200 MeV, 3 GHz linac, a 3 GeV booster, and associated transfer lines. The injection system is designed for top off injection into the storage ring. The linac and booster are envisioned to be turnkey procurements and the transfer lines will be built in house.

The booster is 158 m in circumference with four superperiods and four straight sections. One straight section is for RF, and two others are for injection and extraction. One quarter of the CD-2 lattice is shown in Figure 1. This booster lattice is optimized to have a 35 nm-rad emittance at extraction. This emittance is required to meet the stringent top up injection requirements in the storage ring. Table 1 shows some relevant booster parameters.

The booster injection system consists of a pulsed septum which will deliver the beam with a 7.5 mrad angle into the injection straight. The injection kicker is located 4.2m downstream of the kicker and places the beam on the central orbit. It is shown in Figure 2.

Table 1: Relevant Booster Parameters.

Circumference	158.4 m
Injection Energy	200 MeV
Extraction Energy	3 GeV
Horizontal/Vertical Tune	10.25 / 4.2
Horizontal/Vertical Chromaticity	+1.0 / +1.0
Horizontal/Vertical maximum β	14 / 18 m
Injection Emittance ($4\gamma\beta\sigma_x\sigma_{x'}$)	<55 mm-mrad
Injection Momentum Spread	1% (multibunch)
Aperture	20x12 mm^2 ellipse

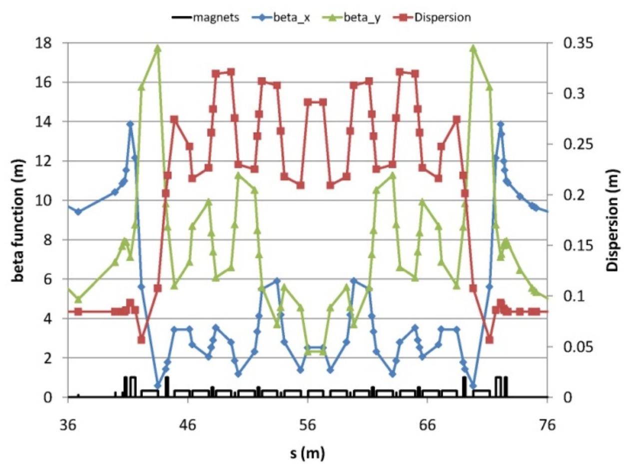

Figure 1: β functions and dispersion function for CD-2 booster lattice.

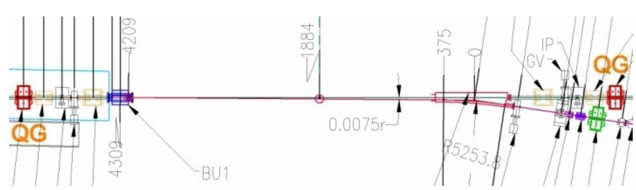

Figure 2: Booster injection straight. The pulsed septum is in red at 0 m. The injection kicker is labeled BU1.

BOOSTER ACCEPTANCE STUDIES

The booster acceptance at the injection kicker was determined in three ways:

1. Linear Calculation
2. ELEGANT simulation with apertures
3. ELEGANT simulation without apertures. [3]

The machine aperture will be an ellipse with horizontal and vertical half axes of 20x12mm^2. The vertical aperture is limited by the gap in the combined function dipoles.

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The linear calculation assumed a constant aperture and determined the maximum offset in the horizontal and vertical position and angle and fractional momentum offset that would be needed to strike the aperture.

The apertures in the ELEGANT simulations are modeled as a rectangle with half height and width given by the aperture in each element, which for most elements is 20x12 mm^2. Radiation damping and excitation were included but are not major effects as the transverse damping time is 16 s at injection. The simulation without apertures was done to determine how much, if at all, the apertures affected the acceptance. Each simulation filled the physical aperture of the booster at the injection kicker, and had a momentum spread of ±5%. The momentum acceptance of the RF was 1.8% in the simulations. $5x10^6$ particles were used in each simulation to ensure adequate phase space coverage. Only 0.08% of them survived the simulation with apertures, 0.8% survived the simulation without apertures. Most particles were lost on the first turn. The simulations lasted 1000 turns.

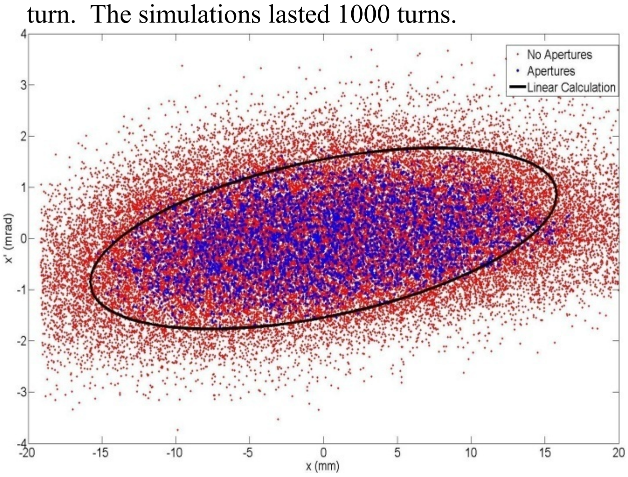

Figure 3: Horizontal phase space acceptance. The black ellipse is calculated from the Twiss parameters, the blue dots are a simulation with apertures, the red dots are a simulation without apertures.

Figure 3 shows the results of the horizontal phase space acceptance and Figure 4 vertical phase space acceptance at the injection kicker. The simulation and the twiss calculation in each plane are in good agreement. The simulations show that the nonlinearities in the lattice are not significantly changing the transverse acceptance. However, it is clear that the apertures are hurting the injection acceptance, particularly in the vertical plane. The flat edges on the aperture-less simulations reflect the extent of the input distribution.

Figures 5 and 6 show how these aperture limitations propagate through the machine in the horizontal and vertical planes. Figure 5 shows that the horizontal aperture limit is the second quadrupole after the long drift space. The first and last dipole in the arcs are the aperture limitations in the vertical plane. We note that these are horizontally defocusing dipoles.

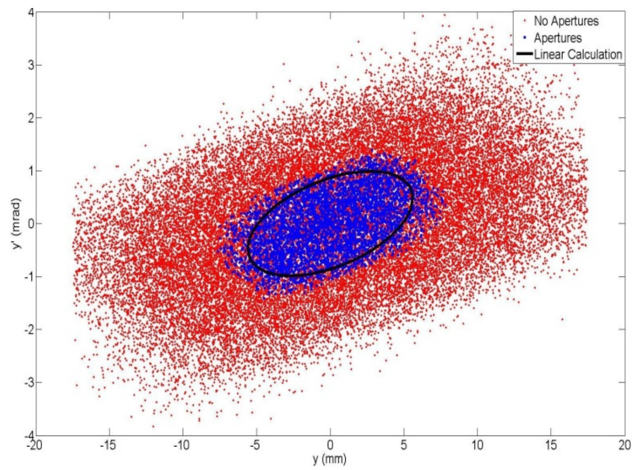

Figure 4: Vertical phase space acceptance. The color code is the same as Figure 3.

The momentum acceptance was found to be 6.2% from the Twiss calculations. This is 3.4 times larger than the RF acceptance. The ELEGANT simulations are limited by the input particle distribution. Figure 5 shows the aperture limitation on the momentum spread. The second horizontally focusing dipole in the arcs is the aperture limit. We note that the energy spread coming from the linac should be less than 1% for multibunch mode and 0.5% in single bunch mode, so we do not anticipate this to be a problem, and are not included in the transverse acceptance calculations.

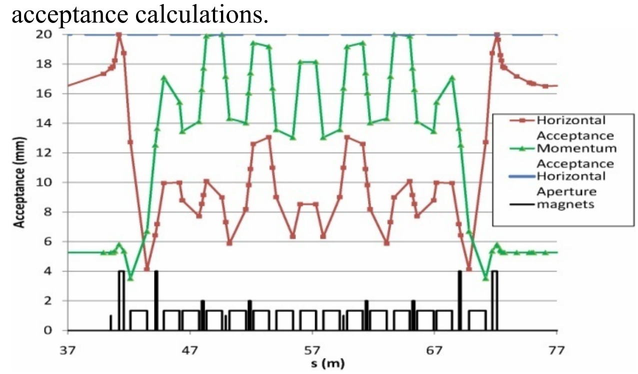

Figure 5: Horizontal and momentum acceptance for one quarter of the booster. Limiting apertures are in the second quadrupole and the second focusing dipole.

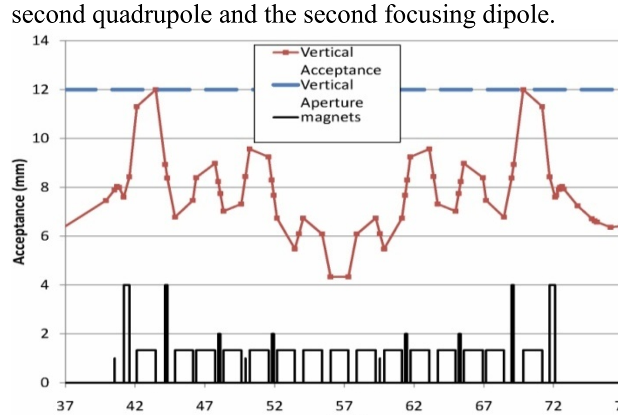

Figure 6: Vertical acceptance for one booster superperiod. The aperture limit is in the first horizontally defocusing dipole.

Table 2: Synopsis of the acceptance studies.

Method	x (mm)	x' (mrad)	y (mm)	y' (mrad)	δ (%)	Horizontal Area (mm-mrad)	Vertical Area (mm-mrad)
Twiss Calculation	15.8	1.7	5.6	1.11	6.2	25	5
ELEGANT with Apertures	15.4	1.7	7.6	1.4	5.0	21	8
ELEGANT no Apertures	20.0	3.7	17.5	3.9	5.0	44	40

DYNAMIC APERTURE

Figure 7 shows the results of 1000 turn simulations of the dynamic aperture of the booster with no errors. Two simulations are shown, one with apertures and one without apertures included. The dynamic aperture is 370 mm^2 at the nominal tune with apertures included, as compared to the physical aperture of 754 mm^2. The dynamic aperture with the apertures included is 1600 mm^2. The physical aperture clearly limits the acceptance of the booster, particularly in the vertical plane.

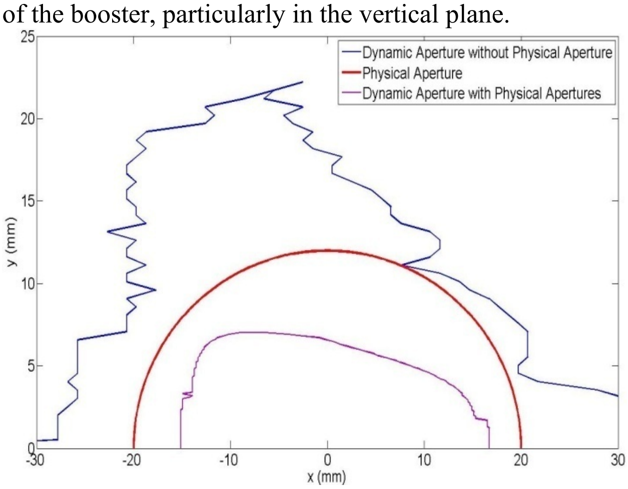

Figure 7: Dynamic Aperture of CD2 booster lattice shown with the physical aperture.

The vertical acceptance limitations come from two sources. The physical aperture is limited by the dipole magnets. Increasing the aperture requires increasing the magnet gap and the cost. The vertical β function entering the dispersion suppressor is quite large. Reducing this will also improve the transverse acceptance. We are currently investigating different options for the lattice design that will reduce the vertical β function. Additionally we are considering widening the dipole magnet gap.

BOOSTER INJECTION SYSTEM TOLERANCES

These acceptance studies allow us to determine some tolerances for the booster injection system. If we consider the septum and kicker independently, then we see that each cannot have a bend angle error or more than 1.7 mrad. The roll angle of the injection kicker is limited to 43 mrad, and the roll angle of the injection septum is limited to 9.8mrad, determined by the coupling into the vertical.[4]

The combined effects of trajectory errors, injection septum, kicker errors, and booster errors have not been studied, but are planned.

IMPLICATIONS FOR TRANSVERSE STACKING

The original plan for transverse stacking in the booster was to inject the first bunch and fire the injection kicker at full strength to place the first bunch on the central orbit. The injection kicker would fire at half strength when the second bunch enters. This would separate the bunches by 3.5 mrad with no initial displacement. This is clearly larger than the horizontal acceptance of the booster. For this reason we are considering a four bump system to do transverse stacking and are no longer considering our initial plan.

CONCLUSION

The acceptance of the CD2 version of the NSLS-II booster lattice was studied. The acceptance is limited by the physical aperture and the large beta functions at the end of the straight sections. Transverse stacking using the original plan is not possible since the horizontal angular acceptance is a factor of two too small.

Because of the lower acceptance than we would have desired we are investigating alternative designs of a booster lattice to increase the acceptance and dynamic aperture. These studies are ongoing.

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[4] R. Fliller III, “NSLS-II Booster Injection Acceptance and Some Relevant Tolerance Limits”. NSLS-II Tech Note 54.