SIMULATIONS OF TRANSVERSE STACKING IN THE NSLS-II BOOSTER*

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Abstract

The NSLS-II injection system consists of a 200 MeV linac and a 3 GeV booster. 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. We have developed a scheme to transversely stack two bunch trains in the NSLS-II booster in order to alleviate the charge requirements on the linac. This scheme has been outlined previously.[1, 2] In this paper we show particle tracking simulations of the tracking scheme. We show simulations of the booster ramp with a stacked beam for a variety of lattice errors and injected beam parameters. In all cases the performance of the proposed stacking method is sufficient to reduce the required charge from the linac. For this reason the injection system of the NSLS-II booster is being designed to include this feature.

INTRODUCTION

The NSLS-II injection system consists of a 200 MeV linac and a 3 GeV booster. The injectors must provide 7.5nC in bunch trains 80-150 bunches long every minute for top off operation of the storage ring. Top off then requires that the linac deliver 15nC of charge once losses in the injector chain are taken into consideration. This is a very stringent requirement that has not been demonstrated at an operating light source. For this reason we have developed a method to transversely stack two bunch trains in the booster while maintaining the charge transport efficiency.

This stacking scheme has been discussed previously.[1,2] In this paper we show the simulations of the booster ramp with a single bunch train in the booster. Then we give a brief overview of the stacking scheme. Following, we show the results of stacking two bunch trains in the booster with varying beam emittances and train separations. The behavior of the beam through the ramp is examined showing that it is possible to stack two bunch trains in the booster.

BOOSTER LATTICE

The NSLS-II booster lattice has been described previously.[2,3] It is has 158.4 m circumference divided into 4 quadrants with 11 FODO cells per quadrant consisting of combined function dipoles. The equilibrium emittance of the lattice is 39 nm. The lattice functions are shown in Figure 1. The physical aperture of the booster is limited by the 20x12 mm^2 aperture in the dipoles. The dynamic aperture is larger than the physical aperture.[2]

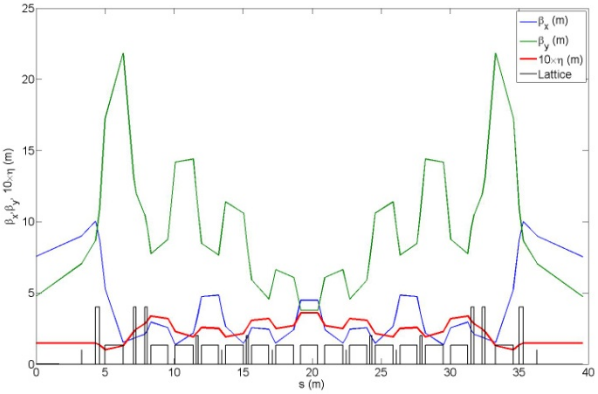

Figure 1: Lattice functions of the NSLS-II booster.

SINGLE BEAM RAMP

The booster ramp is assumed to be cosine ramp with 100ms flat bottom to accommodate stacking and 400ms rise time. This is consistent with a 10 Hz linac repetition rate and a 1 Hz repetition rate of the booster. The RF voltage at injection energy is 200 kV to have sufficient momentum aperture for the injected beam. The phase and voltage of the RF is adjusted during the ramp to increase the beam energy while slowly lowering the synchrotron frequency. This ramp is shown in Figure 2.

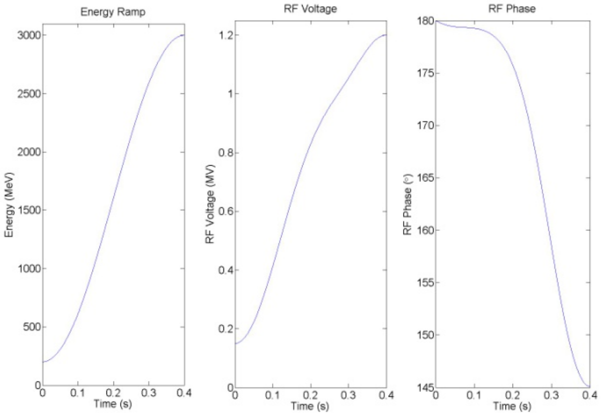

Figure 2: Energy, Voltage and Phase Ramps used for these simulations.

We simulated one bare lattice with 20 seeds containing alignment and field errors [2]. The closed orbit was corrected to within 1.5mm in the horizontal plane and 1.2 mm in the vertical plane. No tune or chromaticity correction was performed. The transverse emittance is 155 nm rms which is 4 times the linac specification. The momentum spread is 0.5% rms with a rms bunch length of 10 ps.

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The bare lattice had 99.5% transmission. The horizontal emittance was 38 nm at the end of the ramp in agreement with calculation.

Of the 20 seeds that were used, all but 4 of the seeds had a transmission of 98.8±1.5%. The remaining four "bad" seeds are not included in further analysis unless specifically mentioned as the charge transmission is uniformly lower than the other seeds. The equilibrium horizontal emittance is 35±2 nm in agreement with calculations. The vertical emittance is less than 2 nm in all cases. Figure 3 shows the evolution of the horizontal beam emittance along the ramp for a seed with high transmission and one with low transmission. The initial drop in emittance is due to adiabatic and radiation damping. The emittance grows at the end of the ramp due to quantum excitation to the equilibrium emittance.

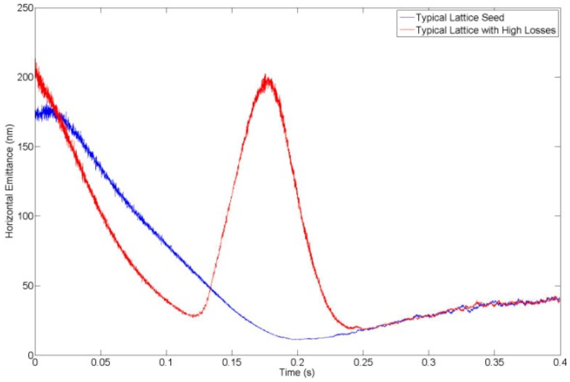

Figure 3: Horizontal Emittance through the energy ramp for a typical seed with high charge transmission (blue) and a typical seed with low charge transmission (red).

The charge transmission of the "bad" seeds is 90±2%, with a 43±2 nm horizontal emittance and 3.6±1.6 nm vertical emittance. Further investigation to the lattice parameters shows that coupling is causing the larger emittances and higher losses. The average coupling integral of the seeds with bad transmission is 13% higher than that of the seeds with good transmission.[4] As Figure 3 shows the evolution of the emittance through the ramp is very different, particularly in the region where the beam emittance is supposed to be a minimum. The vertical emittance shows a similar growth in this area. If the booster exhibited coupling issues, the orbit would be modified and the lattice could be realigned.

STACKING SCHEME

The stacking scheme for the NSLS-II booster has been discussed in previous places so only a brief outline shall be given here. [1,2]

The booster injection straight, shown schematically in Figure 3, consists of four fast kickers and the injection septum. When the first bunch is injected the beam exits the septum parallel to the closed orbit and the second pair of kickers places the beam on the closed orbit. The first bunch train circulates for 100 ms until the next linac pulse. Then the first pair of kickers moves the circulating bunch train outward toward the injection septum, parallel to the closed orbit. The second bunch train exits the septum parallel to the first. The second pair of kickers then places the centroid of the two trains on the closed orbit. This maximizes the available phase space for the stacked trains. The booster ramp proceeds as usual with the beams merging on the ramp through filamentation and radiation damping.

The separation of the two beams is limited by the septum knife thickness and the size of each beam. Assuming a 3 mm knife thickness and a 1 mm clearance for each beam for orbit motion and septum misalignments, the beam separation is

$$\Delta x = 3\sigma_{x1} + 3\sigma_{x2} + 5\text{ mm} \qquad (1)$$

where σ_{x1} and σ_{x2} are the horizontal rms beam sizes of the first and second bunch trains. There is no vertical separation.

Previous analysis has shown that the booster has sufficient acceptance to accommodate both bunch trains even when errors are accounted for [1].

RAMPING WITH STACKED BEAM

Simulations of ramping with a stacked beam used the same twenty seeds as the previous ramping simulations. This was so we could directly compare the same lattices with and without stacking.

We simulated five different cases of beam separation and emittance with each of the twenty seeds. This was to check the robustness of the stacking scheme in cases where injection was not perfect or the linac emittance

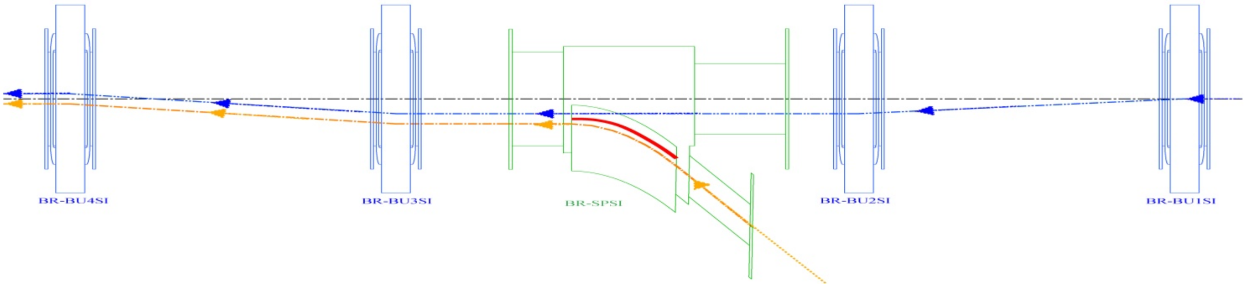

Figure 4: Schematic of injection of the second bunch train into the booster. The first bunch train is shown in blue, the second in orange. The centroid of the bunch trains is placed on the closed orbit during injection.

Table 1: Summary of the Simulation Results of Tracking with Stacked Beams [2]

Scenario	Emittance (nm)	Separation (mm)	Occupied Phase Space (mm-mrad)	Transmission
0	155	0	3.9	99±1%
1	155	13	18.9	91±9%
2	39	13	14.1	93±9%
3	78	11.4	13.8	95±7%
4	39	10.5	10.9	96±6%
5	25	10.14	9.7	96±5%

changed. The energy spread and bunch length were the same as in the single beam case. We used two beams transverse emittances and separations given by Table 1. Each stacking simulation used 1000 particles, 500 per beam.

Scenario 0 is the single beam ramp discussed above. The remaining cases are ordered by the horizontal phase space that the beam occupies. These should be compared with the horizontal acceptance of the booster which is 31 mm mrad. Scenario 4 corresponds to the case where the linac operates at the specified emittance. In all cases except scenario 2, the beams are separated as in Equation 1.

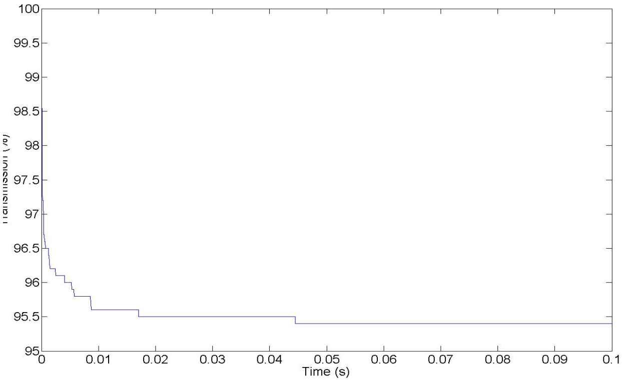

Figure 4: Charge transmission vs. Time during the initial part of the energy ramp for a seed in scenario 4. The transmission is flat after this portion.

The transmission column is the average over all of the seeds not including the above mentioned "bad" seeds with high coupling. There is a clear correlation between the amount of phase space that the stacked beam occupied and the amount of charge that survives to the top of the booster ramp. Figure 4 shows a typical charge transmission curve through the energy ramp for a seed in scenario 4. The losses occur at the beginning of the energy ramp as some particles fall out of the RF bucket. Otherwise there are no further losses. The horizontal emittance evolves similarly as shown in figure 4, the only difference is a larger value at the beginning of the ramp.

Once losses from beam gas scattering are included, the total losses for scenario 4 are 95%. This means that to achieve 15 nC in the booster, the linac needs to deliver 8 nC per shot. This performance is equivalent to what exists at other operating light sources [5].

CONCLUSION

In this paper we detail our simulation of beam stacking in the NSLS-II booster. First we demonstrate how a single bunch train will perform during a booster ramp. The booster has 98.8% charge transmission during a ramp with a single beam even with errors included. We also showed that high coupling is the cause of low charge transmission and larger beam emittance in a limited number of cases.

Then we demonstrate the performance of the booster under five cases of beam stacking. The charge transmission was larger than 90% in all cases, increasing as the phase space of the stacked beam decreased. In most cases the beam loss is very early in the ramp, similar to what we seen with a single beam ramp.

The success of the stacking simulations shows that the NSLS-II booster can accumulate 15nC per ramp by accepting two bunch trains with 8 nC each from the linac. Because of this, we are building the NSLS-II booster with this ability.

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