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SNS Beam in Gap Removal

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Abstract

Stringent particle loss constraints for the SNS accumulator ring require that the beam gap must be kept clean. A fixed amplitude stripline kicker capable of reversing polarity turn by turn is being designed for this purpose. We present simulations of the beam in gap cleaning process, using the ORBIT code and modeling the kicker as a constant amplitude kick of programmable polarity sequence. We find that particles of any particular tune can be removed from the beam in a small number of turns. For distributions of particles with tune spread, we consecutively apply sequences of kicks for different tunes covering the spread. Even for cases of very large tune spread we find that we can extract the gap beam within seventy turns of the accelerator.

1 INTRODUCTION

The accumulator ring of the future Spallation Nuetron Source (SNS) is designed to accomodate 1.5x10^{14} 1 GeV protons. The RF source will contain the bunched beam to 65% of the ring, leaving an 87 meter long gap to facilitate beam extraction. Due to nuclear magnetic H^- stripping during injection, nuclear scattering at the foil, and collimation inefficiency, some 1x10^{10} particles will find their way into the gap, where they would be subjected to extraction kicker rise and fall feilds. Loss of these particles due to the feilds translates into 200 W of power impacting the beam pipe and other acclerator hardware within the vicinity of the extraction kicker [1]. Normal anticipated losses around the ring are 1 - 2 W/M, and anything beyond this is considered a major radiation hazard that will impede routine beam maintanence and have detrimental effects on the lifetime of the lattice.

Maintaining the 1 - 2 W/M loss limit for the normal beam is achieved via the use of collimators acting as strict aperture enforcers around the ring. These collimators are predicted to minimally absorb 95% of particles that exceed the dynamic aperture. For the beam in the gap, however, most of the particles do not exceed the dynamic aperture and therefore will not reach the collimation system without intervention.

The aim of the Beam in Gap (BIG) project is to utilize fast vertical kickers to kick the gap particles into the collimation system. The kickers will impart a once per turn momentum kick of about 1 mrad. The polarity of each kick can be chosen so that a sequence of kicks is resonant with the betatron oscillation, thereby employing betatron pumping to drive the particles to the collimators in a controlled fashion. One variant of this method has been successfully tested in electron storage machines [2], and another is currently undergoing pilot experiments in hadron machines at HERA [3]. Here, we present computer simulation of the proposed method using the ORBIT code [4], a ring simulation program developed and maintained at ORNL.

2 SIMULATION

2.1 The Model

The hardware that will provide the requisite kicks consist five vertical stripline kickers operating in the TEM mode, with cummulative kicking strength of 1 mrad. For simplicity, in the simulation we model the kicker with one, 1 mrad kicker, capable of reversing polarity according to a predefined sequence. We determine the kicking sequence by tracking the beam centroid around the phase space and assigning an up kick when the centroid momentum is positive, and a down kick when it is negative. For example, tracking a centroid with fractional tune .8 around the phase space, the kicking sequence would be five turns long, and would begin with a +1 mrad kick (first kick polarity is arbitrary), and be followed in a respective fashion by +1, -1, -1, and, +1 mrad kicks. Though the effect of a kick on each individual particle is sensitive to the particle's phase, using the centroid in this manner garuantees us that the net effect is always to increase the magnitude of the momentum in the distribution.

For very small tune spreads, it is only necessary for the sequence of kicks to follow the main tune of the lattice. However, SNS expected tune spreads are finite and on the order of $1.5 - 0.2$. The intensity of the gap beam is sufficiently low enough so that space charge is not the primary mechanism contributing to tune spread in the gap. Rather, since most particles arriving in the gap have undergone some phenomenon which has altered their energy, chromatic effects become the main cause of tune spread. These effects have been implemented in the simulation through the inclusion of second order transfer matrices in the lattice. The matrices are derived from a perturbative standpoint [5] and therefore are not simplectic. However, the threshold for non-negligible effects due to non-simplecticity occurs well beyond iteration numbers used in the simulation, so for our purposes the approach is very acceptable.

For SNS tune spreads, kicking on resonance with just the central tune will only ensure that some fraction of particles will be excited, that number becoming smaller as more kicks are applied due to Landau damping. Instead, we find resonance sequences for a number of tunes inside the tune spread, and apply sequences one after another to form one long sequence. The result is that several tunes are excited at different times in the sequence, determined in part by constructive and destructive interference between resonances.

Once a particle is in resonance with the kicks, it is important that it reaches the collimator quickly before Landau damping occurs. The closer a particle's tune is to the resonance tune, the faster it's momentum increases and the longer it stays in resonance. This effect is demonstrated in Figure (1), where the tune peak is shown at progressively later times while the kicker is fired at a single resonant frequency. Note how the width of the peak decreases at time increases.

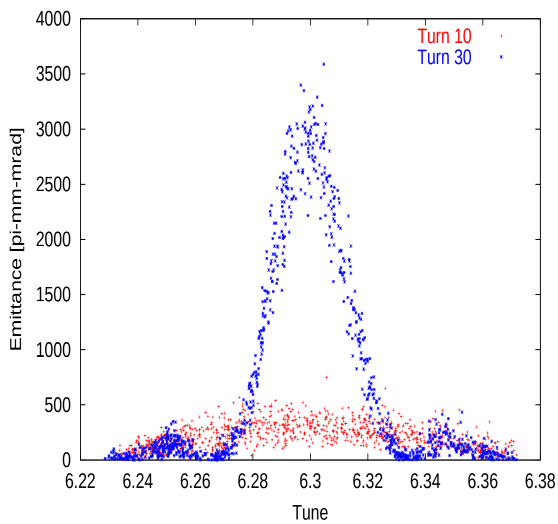

Figure 1: Emmitance vs. Tune after 10 turns and 30 turns of the beam, with the kicker firing on resonance with $\nu = 6.3$.

Ulitimately, the chosen kicking sequence is a compromise between a long sequence of kicks with many resonant tunes (for a broad range of extraction), and a short sequence of kicks with few resonant tunes (for fast extraction).

The efficiency of the gap cleaning process is also highly dependent on the ability of the collimation system to properly distribute and absorb the incident particles. A collimation simulation package which includes all of the relevant physics has been written and is currently undergoing benchmark simulations. This collimation system accurately reflects both the aperture and the geometry of the actual SNS collimation scheme, but for our simulations here the collimator material is taken as a black absorber until benchmarking of the physics is complete.

The collimation system contains eight components, broken down into four primary collimators and four secondary collimators [6]. The primary collimators are short platinum scrapers whose main function is to scatter the particles into high emittances. Four long copper absorbers are then stragically place downstream to intercept these high emittance particles. The scrapers have movable apertures from $\epsilon = 120 - 160\pi$mm·mrad, allowing for flexibility in beam cleaning, while the absorbers are fixed at 300π mm·mrad, well inside the 480π mm·mrad beam pipe aperture.

Lastly, the lattice used in the simulations is the official SNS ring lattice with working points ν_x=6.4 and ν_y=6.3, but containing only first and second order magnetic elements (no sextupoles) and excluding errors. A gaussian beam of 10^4 particles with $\epsilon = 120\pi$mm·mrad and variable energy spread was used for the distribution. Table 1 summarizes the simulation parameters.

Table 1: Simulation Parameters

Emittance (99)	120 (π mm·mrad)
Distribution Type	Gaussian
Energy Spread	Variable, 0.007 - 0.01
Kicker Strength	1 ($mrad$)
Primary Collimator Aperture	140 (π mm·mrad)
Secondary Collimator Aperutre	300 (π mm·mrad)
Beam Pipe and Magnet Apertures	480 (π mm·mrad)

2.2 Results

The momentum aperture of the RF bucket is $\delta = \frac{\Delta P}{P} = 0.01$. The tune spread due to chromatic effects for a beam which spans this momentum aperture is $\Delta\nu \cong 0.14$. The kicking sequence for this distribution is choosen so that one resonant sequence of variable length occurs every 0.03 tunes. Figures (4) - (6) show time snapshots of the beam particles for this distribution ($\delta = \frac{\Delta P}{P} = 0.01$.) as they rise towards the collimators, where they are absorbed. Note that the phase of the particles may dictate that they reach the required emittance aperture for absorption several turns before actually making contact with the primary collimator. During the interim, if a particle is still undergoing resonance, it's emittance may grow enough so that it bypasses the primary collimators altogether and impacts the secondary instead. For this particular case 81% of particles impact the primary collimator, and the remaining 19% impact the secondary, with no impaction on either the beam pipe or the magnets. In addition, all of the particles impact the collimator within 40 turns around the accelerator.

As previously stated, the speed at which we can extract particles from the beam gap is a function of the number of tunes we include in the resonant sequence. Naturally, this choice will depend mostly on the width of tune spread, which in turn depends on the fractional momentum deviation δ. The anticipated momentum deviation in the normal (non-gap) portion of the beam is 0.007. The RF bucket contains up to $\delta = 0.01$ and the dynamic aperture of the lattice up to $\delta = 0.02$. We expect that gap will have δ at least somewhat larger than the anticipated normal beam value, but still smaller than the dynamic aperture. Figure (2) shows the cleaning efficiency for beams with momentum spreads equal these three values. In the worst case, we are able to extract the beam within 70 turns, while in the best case we can reduce this number by over half.

3 CONCLUSIONS AND FUTURE WORK

The results of the simulations indicate that this method may be a viable candidate for gap cleaning in the SNS ring. Although results up to this point appear very promising, it is important to recognize that the collimation process will play an important role in determining the overall success of gap cleaning. The collimation routine currently undergoing benchmark simulations is a detailed model of the phenomenon of protons traversing dense blocks of matter of varying shapes, and is designed specifically for low energy protons ($\leq$ 1.5 GeV). Once in full operation, the routine will provide a complete account of both the normal collimation function in SNS as well as the beam in gap cleaning process. In addition, we intend to include the effects of transverse and longitudinal impedances, which can complicate the cleaning process by introducing halo and other instabilities in the gap beam.

4 REFERENCES

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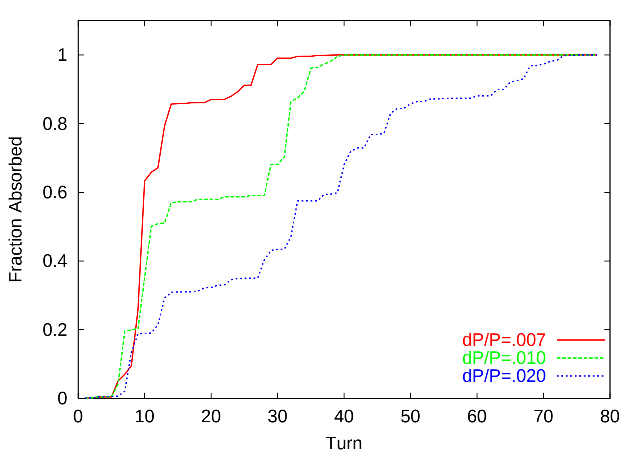

Figure 2: Fraction of particles absorbed per turn for momemtum deviations corresponding to the anticipated momenutum spread (0.007), the RF momentum aperture (0.01), and the dynamic aperture (0.02).

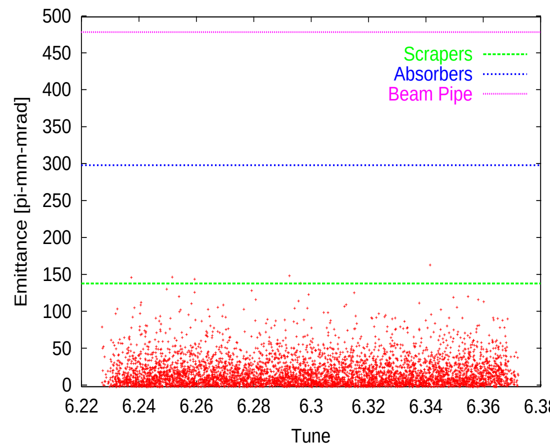

Figure 3: Emmitance vs. Tune before kicking for a distrubition with $\delta = \frac{\Delta P}{P} = 0.01$.

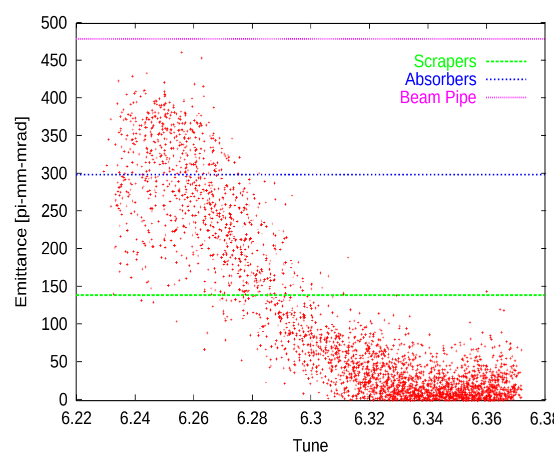

Figure 4: Emmitance vs. Tune after 10 turns. Note that because of the phase dependence of the betatron motion, some particles climb to very high emittances before making contact with the collimation system.

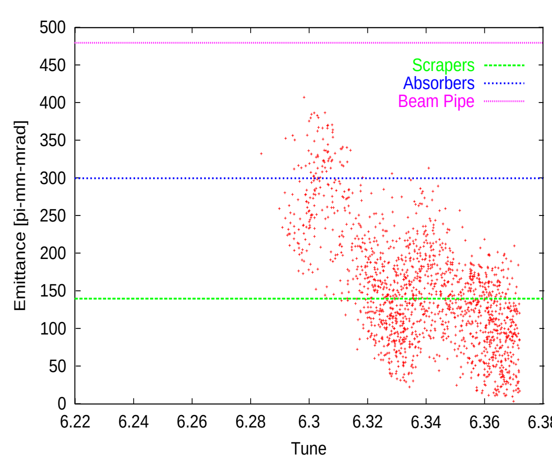

Figure 5: Emmitance vs. Tune after 30 turns. In this example, all of the particles are absorbed by turn 40.