LINAC ENERGY MANIPULATION FOR LONGITUDINAL PHASE SPACE PAINTING FOR SNS RING*

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Abstract

Control of instabilities and halo losses are important issues for a high beam power storage ring like the Spallation Neutron Source (SNS)**. One of the important issues is proper transverse and longitudinal phase space painting. The former is well studied and in this paper we discuss a robust way to achieve longitudinal phase space painting into a ring. Energy jitter correction and programmable energy spread are essential for controlling losses during the 1000 turn injection into the accumulator ring. Energy correction is needed to combat linac cavity amplitude and phase errors. Adequate energy spread is required to provide Landau damping in the accumulator ring during the accumulation process. Two CCL cavities, one for energy correction and the other for creating energy spread, are used for this purpose.

1 INTRODUCTION

High power proton accelerators, like the under construction SNS, of over a mega-watt of beam power face many challenges. Some examples are beam losses caused by space charge effects, injection and extraction processes, and longitudinal and transverse instabilities. Many schemes to reduce the line density of the injected charge have been studied. Ideally, however, one would like to minimize the charge density in six dimensional phase space of the injected ring. A careful manipulation of the linac beam in both transverse and longitudinal phase space, and control of the injection orbit are essential for operation. In the 5 mega-watt European Spallation Source (ESS) design, both the longitudinal and horizontal phase spaces are painted by programming the linac energy and the storage ring rf and coupling the transverse phase space while vertical phase space is painted by orbit bumps.[1] For SNS we are implementing an injection system which separates all transverse and longitudinal phase space, and enables one to program each dimension orthogonal to the others. We achieve this by injecting into a dispersion free section of the ring and using two independent, programmable orbit bumps. While transverse painting is important for the space charge effect, longitudinal painting is essential for controlling space charge and any instabilities by Landau damping. Electron cloud in a ring, which is responsible for the instability seen at the Los Alamos National Lab. PSR, is suppressed by smoothing the bunch shape and the instability is suppressed by large momentum spread. Electron cloud can effectively controlled by shaping the line density of the proton bunch.

2 SNS ACCUMULATOR RING

The function of the SNS accumulator ring is to accumulate linac beam over a thousand turns in a short bunch about 700 nano-seconds long, and extract into the neutron production target. Care is taken to insure hands on maintability of the ring components by minimizing uncontrolled losses of the proton beam. The ring is four fold symmetric and consists of four arcs and straights. The lattice is arranged such that all straights are dispersion free. The straights are for injection, collimation, RF and extraction. One can decouple transverse and longitudinal phase space painting in the ring because of the dispersion free injection straight. The linac beam is pre-chopped to ~650 nsec with ~300 nsec gap and injected into the standing RF bucket of the ring. Various longitudinal painting schemes had been examined in order to create a smooth distribution inside the bucket. The ring RF system keeps the protons bunched and the extraction gap clean, so that extraction kicker rise will not cause any beam loss on the extraction septa. The RF system is dual harmonic, i.e. a fundamental harmonic and a smaller second harmonic to reduce the maximum line density of the protons. The synchrotron period of the ring is about 1 m-sec which is about the injection time. This synchrotron period is significant on smooth painting of the longitudinal phase space. Lack of synchrotron period some difficulties for smooth distribution of the longitudinal phase space. Transverse phase space painting and optimisation have been discussed elsewhere[2] and only longitudinal phase space painting will be discussed here.

3 LONGITUDINAL PHASE SPACE PAINTING

Longitudinal painting is to control two things. One is to paint the phase space as uniformly as one can and the other is to reduce the longitudinal halo. The longitudinal halo is caused by injecting off momentum or at the wrong phase, or by some instability. Stability of the linac energy plays an important in controlling the phase space distribution. Because of the practical limitation on accuracy of amplitude and phase control of the linac tanks, there is irreducible energy error at the output of the linac. Though the emittance of the linac is generally small

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compare to that of the ring, one may want to shape the size of the brush to be used for painting longitudinal phase space by manipulating the energy and energy spread of the linac beam.

3.1 Linac energy manipulation

One way to manipulate the linac energy is to use the phase and/or amplitude of the last accelerating tank RF. By changing the phase of the tank one can increase or decrease the output energy of the proton. During injection the linac energy can be ramped. One can even ramp the energy back and forth a few times. Also by accelerating on the reverse slope of the sine wave one can increase the energy spread.

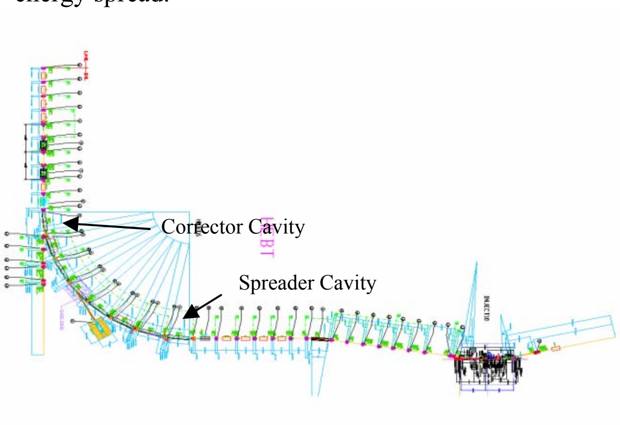

Figure 1. HEBT transport line and the location of corrector and spreader cavities.

Energy error can be corrected with the energy corrector cavity located some distance downstream of the last tank. Fig.1 shows the locations of the corrector and spreader cavities. Using energy dependent phase slip, energy error can be corrected by a RF cavity of suitable amplitude and phase. The limit of correction is from the phase error at the last tank. At SNS, the RF cavity is to be installed in the High Energy Beam Transport (HEBT). This cavity also can spread the energy i.e. enlarge the brush painting the phase space in the ring by running the cavity in 180^o out of phase. Although this method can spread the energy by desired amount, it will also amplify the energy error instead of correction. This also spreads the energy tail further out, and can create longitudinal halo by injecting at wrong energy. This halo can migrate into the extraction gap and cause a beam loss during extraction.

The SNS employs another RF cavity in the HEBT line, the energy spreader cavity. The amplitude of RF in this cavity determines the amount of energy spread and the width of the brush we paint the longitudinal phase space with. This cavity runs at a frequency about 100KHz different from the linac frequency. Since beam and cavity frequency differ by 100KHz, the beam energy will be modulated by a beat frequency of 100KHz. Results from beam tracking, integrated for the entire injection period, are shown on Fig. 2. The width of the energy spread is controlled by RF amplitude of the cavity. Simulations using a debuncher cavity are shown for comparison. Since the spreader cavity only translates the energy, there is no energy tail in this scheme while the other scheme produces a very long energy tail which can cause the protons to spill over into the extraction gap.

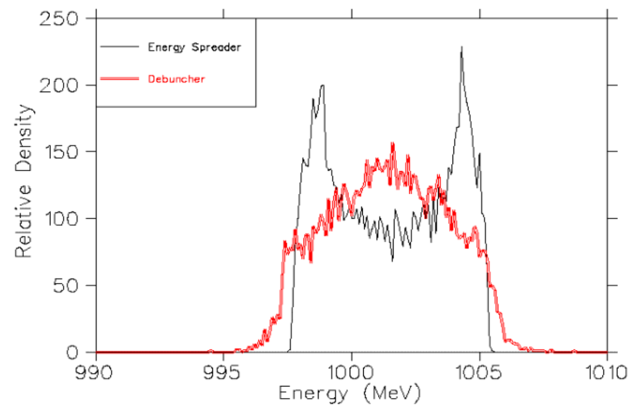

Figure 2. Time integrated energy distribution using constant amplitude energy spreader cavity(black) and debuncher cavity(red).

3.2 Phase Space Painting Comparison

Using the program ACCSIM[3] we simulated injection, ramping the energy using RF phase of the last accelerating tank. The tank phase is varied to produce energy sweep between –4.5 to +4.5 MeV four times during a injection cycle, and the result is shown in figure 3. As can be seen in the figure, the phase space distribution is not smooth and quite lumpy. The phase and energy projection seems somewhat lopsided but reasonable.

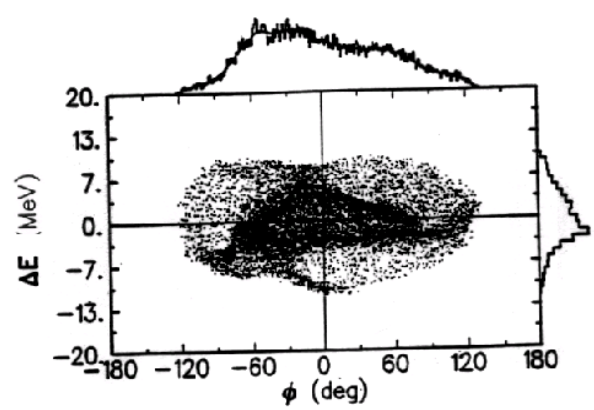

Figure 3. Longitudinal phase space distribution using energy ramping by last accelerating tank.

The same program is used to simulate the distribution using the energy spreader cavity with the amplitude of 4.5 MV, a much smoother distribution is obtained. (Figure 4)

As a summary, the line density plot of cases with energy corrector on/off and energy spreader on/off are shown in figure 5.

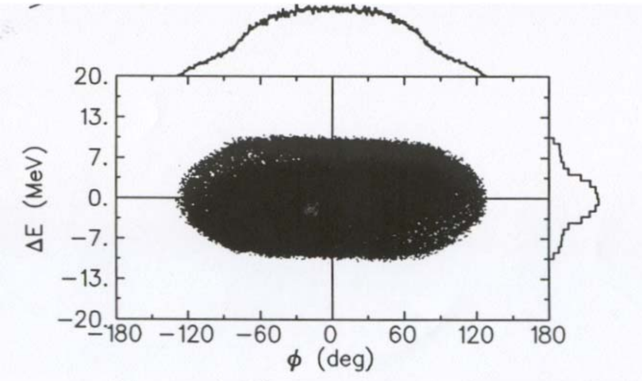

Figure 4. Simulation with energy spreader cavity

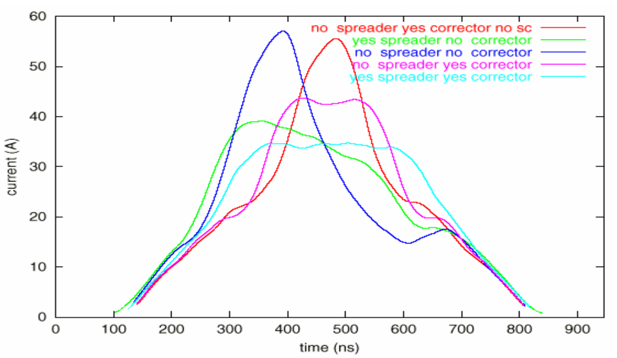

Figure 5. Longitudinal line density distribution for various combinations of cavities

Five simulations are shown, 1) Only energy corrector is on without space charge effect.(red), 2) Same with space charge effect(violet), 3) Only spreader cavity is on(green), 4) Both cavities off(dark blue), and 5) Both cavities on(light blue). A probable linac energy error is incorporated in the simulations. From the figure it is obvious that the energy spreader cavity is an effective device to control the longitudinal phase space distribution in an accumulator ring.

4 DISCUSSION

An energy spreader cavity is a useful device for longitudinal phase space control. However, large energy spread introduces large tune spread, which is indicated in figure 6. The plot shows the cases of $\Delta p/p$=0.7% with natural chromaticity. The red dots, which correspond to momentum spread when the space charge tune shift is minimal, cross several resonance lines. Later in the injection cycle the space charge tune shift lowers the tunes sufficiently to pull the tunes away from the resonance. Although strength of the resonance is not strong enough to cause any concerns, it is best not to cross the resonance early in the cycle. The amplitude of the spreader cavity can be small at the beginning but ramped up. This allows small momentum spread at the beginning of the cycle and gradually higher spread as space charge and the threat of instabilities kick in.

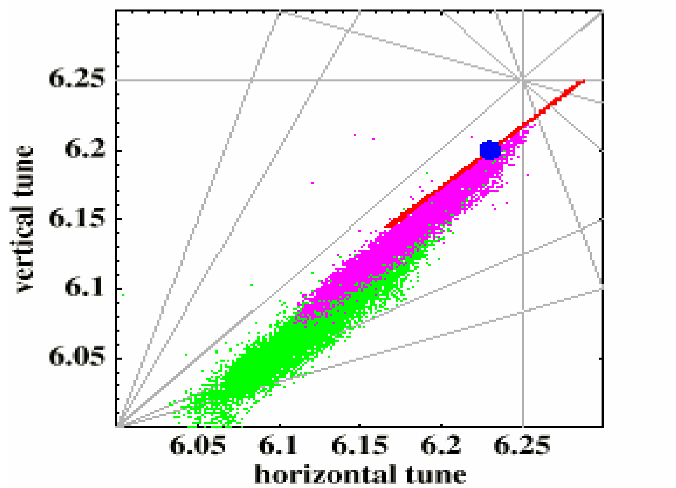

Figure 5. SNS nominal tune diagram with tune distribution, without space charge(red) and with space charge $1\text{x}10^{14}$(pink) and $2\text{x}10^{14}$ (green) in the ring.

A study for refinement of the line density is under consideration. For example, one can shape longitudinal line charge density by programming the chopping pulse length of the linac beam and the amplitude of the spreader cavity through out the injection period so that the edge of the brush follow the separatrics contour.

5 ACKNOWLEGEMENT

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6 REFERENCES

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