STUDY OF LONGITUDINAL INJECTION/STACKING IN THE SNS ACCUMULATOR RING*

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Abstract

Various longitudinal distributions, resulting from the specific injection and stacking methods, are considered to minimize longitudinal and transverse instabilities and particle losses in SNS accumulator ring. The longitudinal phase space paintings by linac energy ramping, increased linac energy spread and the use of a random phase RF debunching cavity are reported. Bunch lengthening and beam in gap rate as functions of injection energy spread, RF voltage and injection energy error is summarized. Finally, the energy error tolerance is concluded.

1 INTRODUCTION

At Brookhaven National Laboratory work is in progress for the design and construction of a proton accumulator ring for the spallation neutron source (SNS) [1]. One of the performance requirements of the Spallation Neutron Source (SNS) is to keep the uncontrolled beam loss in the accumulator ring to < $2\mathrm{x}10^{-4}$ /pulse. In order to lower the *e-p* instability threshold and to reduce the extraction beam loss, it is essential to produce a longitudinal distribution that has broad energy spread, uniform distribution and clean gap. This study is devoted to longitudinal injection/stacking. The study on transverse phase space painting and related issues are reported separately [2].

The investigations are performed by tracking 10^5 macro-particles in full 6-dimensions through the ring lattice, in the presence of space charge, with the simulation code ACCSIM [3]. The initial longitudinal distribution of injected pulse is Gaussian in energy and uniform in time. All the physical quantities used in the simulations are chosen to be as close as possible to the specifications in the current design [4]. The lattice functions [5] and other salient parameters used in the study are listed in Table 1.

Table 1 Design parameters used in the simulation study.

Beam Kinetic Energy	1 GeV
Beam Average Power	1.0-2.0 MW
Beam Emittance $\varepsilon_{x,y}$	120 πmm-mr
Tunes ν_x / ν_y	5.82 / 5.80
Max. β_x / max. β_y	19.2 / 19.2 m
Dispersion X_p (max/min)	4.1 / 0.0 m
Injection Pulse Length / Gap	546nsec / 295nsec
Extraction Pulse Length / Gap	591nsec / 250nsec
RF Voltage (1st / 2nd harmonic)	40 kV / 20 kV

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2 EFFECTS OF ENERGY RAMPING

One of the easiest ways to increase the energy spread is to paint longitudinal phase space by energy ramping. During the injection, the energy may be ramped in any combinations of linearly/nonlinearly, up/down towards/away from the designed energy as function of time. We demonstrate, in Fig. 1 and Fig. 2, two longitudinal phase space painting results from the two basic methods of energy ramping shown in Fig.3 (a) and (b), respectively. Other painting schemes are variations of these two. It was found that various undesirable annular structures were developed during the painting depending on the ramping schemes. Because the injection time is comparable to the synchrotron oscillation period, the injected particles do not have enough time to redistribute through synchrotron oscillations. Therefore, energy ramping does not provide a satisfactory longitudinal particle distribution in the SNS accumulator ring.

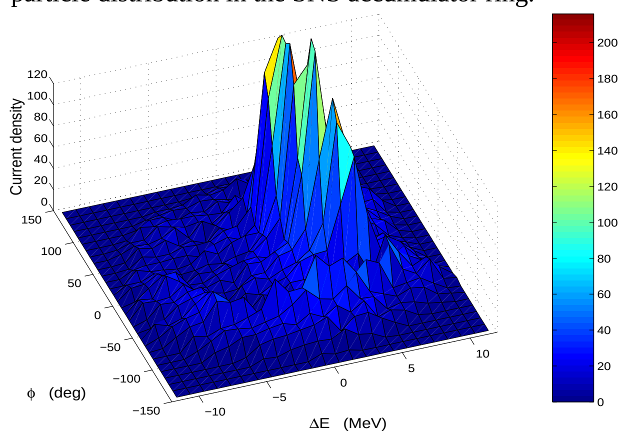

Fig. 1 Current density distribution in longitudinal phase space obtained by energy ramping illustrated by Fig. 3(a).

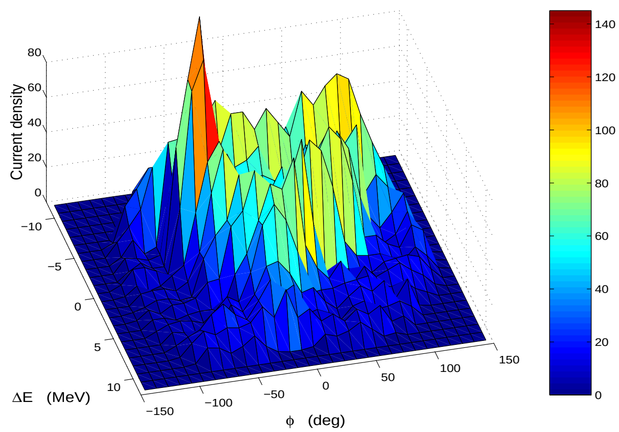

Fig. 2 Current density distribution in longitudinal phase space obtained by energy ramping illustrated by Fig. 3(b).

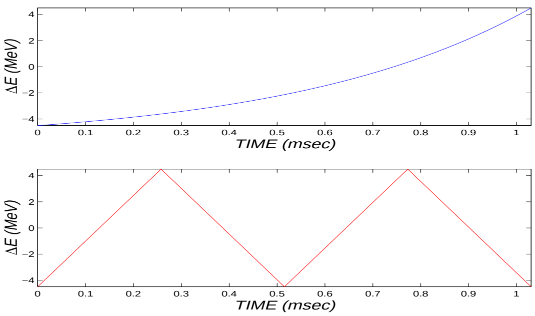

Fig. 3 Two basic energy ramping schemes. (a) Nonlinear monotonic, (b) linear non-monotonic during the injection.

3 EFFECTS OF LINAC ENERGY SPREAD

In order to investigate the effects of increased linac energy spread, the longitudinal phase space distributions for σ_E=1-4MeV in 1MW and 2MW beams were produced by computer simulations. As examples, Fig. 4 and 5 show the current density profiles in longitudinal phase space for the cases of σ_E=1MeV and 2MeV in a 2MW beam. These profiles indicate that increasing linac energy spread is an effective method of broadening beam energy spread. However, the particle leakage to the gap is associated with the broad beam energy spread. Fig. 6 shows the particle in gap rate vs. injection energy spread σ_E. Considering the beam loss requirement of SNS, energy spread σ_E has to be limited to 1.5MeV if injected linac beam has long tails.

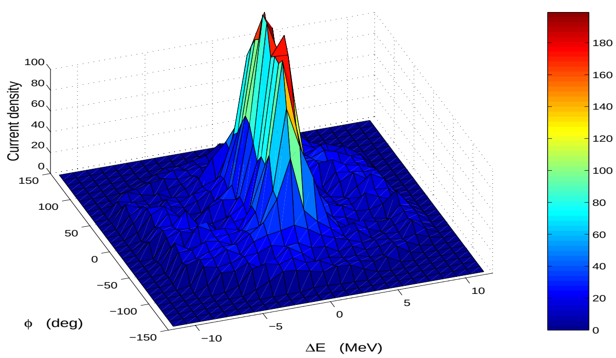

Fig. 4 Current density distribution in longitudinal phase space obtained by 1225 turns of injection/stacking with injection energy spread σ_E=1MeV and truncation of 5σ_E.

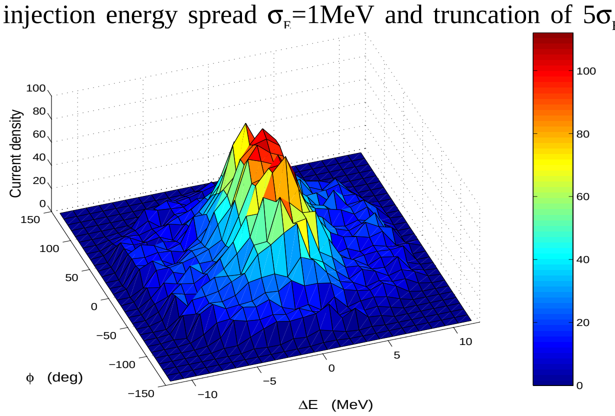

Fig. 5 Current density distribution in longitudinal phase space obtained by 1225 turns of injection/stacking with injection energy spread σ_E=2 MeV and truncation at 5σ_E.

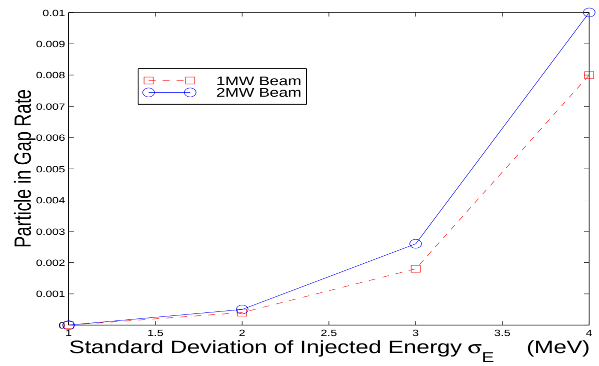

Fig. 6 Particle in gap rate vs. injection energy spread σ_E in 1MW and 2MW beams.

4 EFFECTS OF DEBUNCHING

A random phase RF debuncher in the pre-injection line for increasing momentum spread was proposed in BNL [6]. By modulating RF frequency to mismatch the beam with RF frequency, the individual micro-bunches effectively get a random energy kick which increases the rms momentum spread of linac beam. Fig. 7 gives a beam profile obtained by computer simulation applying such random phase debuncher. As a result, the injection energy spread is broadened to $\sigma_E \approx$5MeV without any tail enhancement. Simulation shows, see Fig. 8, that the injection/stacking with such energy distribution, gives a beam with broad energy spread and maintains a clean gap.

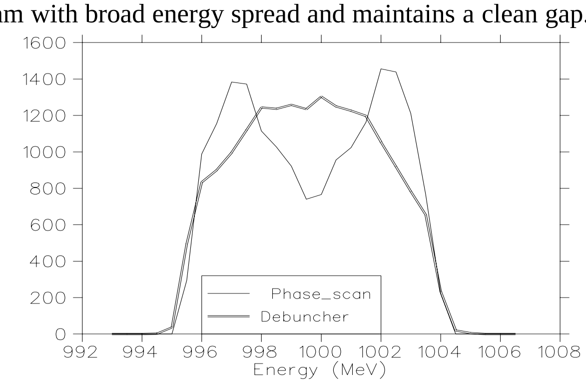

Fig. 7 Beam profile obtained by simulation applying random phase debuncher and conventional debuncher.

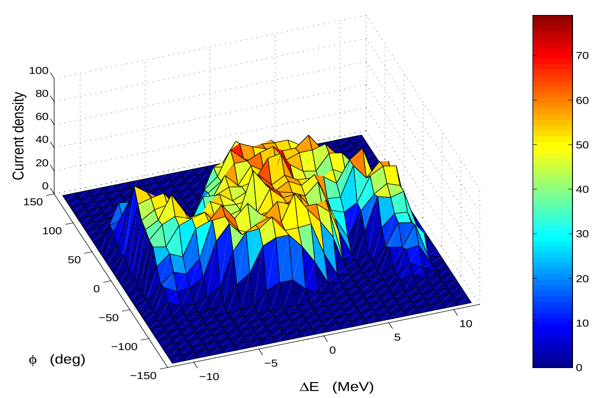

Fig. 8 Current density distribution in longitudinal phase space obtained by injection/stacking with injection energy spread σ_E=5MeV and truncation at 5MeV.

4 BEAM LOSS VS. RF WAVEFORMS

Two major factors leading to longitudinal beam losses are bunch lengthening and particle leakage to the gap. Previous work [7, 8] has established that a dual-frequency RF system has significant advantages over a single-frequency system on beam handing. In the current dual-frequency RF system design, the 1st and 2nd harmonic has voltage of 40kV and 20kV respectively. In order to make a realistic comparison of dual-frequency and single-frequency RF system on the effects of longitudinal beam loss, we study single-frequency at 40kV and dual-frequency at 40kV and 20kV, for the 1st and 2nd harmonic, with identical physical conditions. The simulation results of the effects of dual-frequency and single-frequency RF systems on bunch lengthening and particle in gap rate at the end of 1 MW injection/stacking (with tail truncation at $5\sigma_E$) are summarized in Table 2 and 3 respectively.

Table 2 Bunch lengthening (nsec) versus RF waveforms and voltages with injection energy spread σ_E =1, 2, 3MeV.

		Injection Energy Spread σ_E		
		1MeV	2MeV	3MeV
Single-freq. RF	40 kV	19	46	84
Dual-freq. RF Voltage (kV) ($1^{st}/2^{nd}$ harm.)	40 / 20	19	23	37
	36 / 18	21	30	
	30 / 15	23	42	
	20 / 10	37	107	

Table 3 Particle in gap rate (10^{-4}) versus RF waveforms and voltages with injection energy spread σ_E =1, 2, 3MeV.

		Injection Energy Spread σ_E		
		1MeV	2MeV	3MeV
Single-freq. RF	40 kV	2.9	8.9	28.7
Dual-freq. RF Voltage (kV) ($1^{st}/2^{nd}$ harm.)	40 / 20	0	4.5	22.0
	36 / 18	0.1	5.1	
	30 / 15	0.3	5.7	
	20 / 10	1.8	46.4	

5 ENERGY ERROR TOLERANCE

If the injected linac energy is slightly different from the design energy of the accumulator ring, undesirable annular structures may develop in the longitudinal phase space distribution, which may cause instabilities and beam losses. The energy error tolerance is crucially dependent on injection energy spread σ_E and RF voltages applied. Bunch lengthening and particle in gap rate as functions of injection energy error with various injection energy spread σ_E (with tail truncation at $5\sigma_E$) and RF voltages are show in Fig. 9 and Fig. 10 respectively, which are obtained from simulations of 10^5 macro-particles during 1225 turns of injection/stacking. The statistical fluctuation is ~10%. From this study we give, in Table 4, the energy error tolerance versus injection energy spread σ_E and RF voltage for 1MW SNS accumulator ring injection. The tolerance level can be expected to be lower for the 2MW injection.

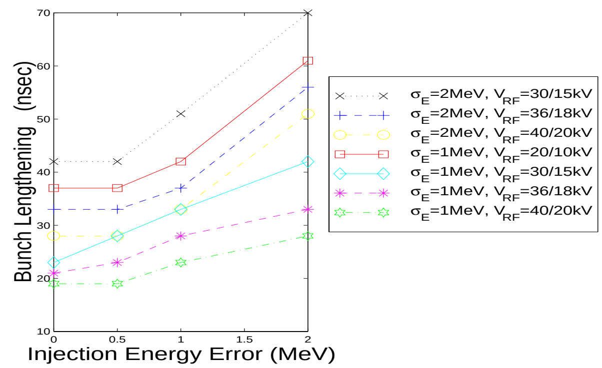

Fig. 9 Bunch lengthening versus injection energy error.

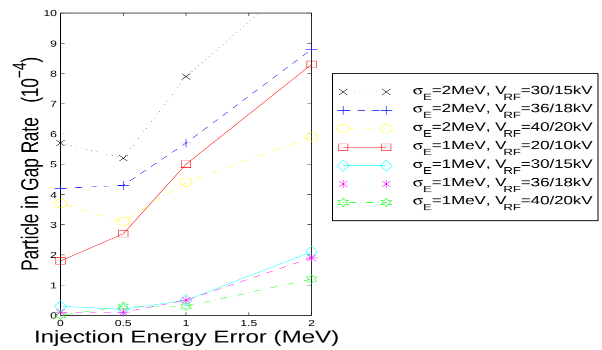

Fig. 10 Particle in gap rate versus injection energy error.

Table 4 Injection energy error tolerance versus injection energy spread σ_E and RF voltage.

RF Voltage ($1^{st}/2^{nd}$ harm.)	Injection Energy Spread σ_E		
	1 MeV	2 MeV	3 MeV
40kV / 20kV	< 2MeV	N. A.	N. A.
36kV / 18kV	< 1.5MeV	N. A.	N. A.
30kV / 15kV	< 1MeV	N. A.	N. A.
20kV / 10kV	0MeV	N. A.	N. A.

N. A. = Not Acceptable

6 ACKNOWLEDGEMENT

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7 REFERENCES

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