BEAM BUNCH LEAKAGE AND CONTROL IN THE SNS RING*

Y. Zhang, J. Galambos#
Spallation Neutron Source, ORNL, Oak Ridge, TN 37831, U.S.A.

Abstract

In the previous neutron production operations at the SNS, the longitudinal extraction gap of the accumulator ring was contaminated as a result of the linac chopper limitations. This caused significant beam loss and activation in the ring and in the extraction beam line. Simulations with computer models and measurements showed that proper use of the ring RF systems, with additional storage turns after the necessary beam accumulation turns in the ring, effectively reduced beam loss in the accelerator systems. Simulations and beam measurement results will be discussed.

INTRODUCTION

The Spallation Neutron Source (SNS) is a short-pulse neutron scattering facility. Its accelerator complex consists of a 2.5 MeV H^- injector, a 1 GeV linac, a 248 m accumulator ring and associated beam transport lines. In the baseline design, a 25 μC proton beam is accumulated in the ring over 1060 turns. When accumulation is complete, the extraction kicker fires during a 250 ns gap to remove the accumulated beam in a single turn and directs it into the Ring to Target Beam Transport (RTBT) line, which takes the beam to a liquid-mercury target [1].

Pre-chopping is performed by the low-energy beam transport (LEBT) chopper, which deflects 32% of the beam onto the front face of the RFQ with a design rise/fall time of 40 ns. In the medium-energy beam transport (MEBT) line, a fast chopper system with a 10 ns rise/fall time removes the "partially chopped" beam from the LEBT chopper and further reduces the beam extinction ratio to below 10^{-4} [1]. During neutron production runs in early 2007, the resistance of the choppers had to be increased to protect the LEBT systems because of frequent ion source discharges and the MEBT chopper was not functional. Beam contaminated the extraction gap as the rise/fall time of the linac choppers increased, and the contamination caused significant beam losses and activations in the ring and in the RTBT line.

While awaiting a time-consuming final fix of the LEBT problems, SNS continued neutron production and meanwhile mitigated beam loss and activation. Storing beam by appropriate additional turns after the beam accumulation turns and using the dual-harmonic ring RF system to clean up most of beams in the gap, first proposed several years ago [2], was tested.

MODELS

Two tracking codes for particle beams are used in the simulations, ORBIT [3] and RFsimulator [4] - both are developed at SNS. ORBIT is a parallelized code in C++ for a ring; beam collection effects, such as: space charges, wakes and impedance of the ring, are included in the simulation. RFsimulator, written in Java, uses a ring model without acceleration or space charge, but beam loading in the RF cavities and most of the realistic features of RF controllers – including feedback and feed forward, loop gain and loop delay, bandwidth, dynamic cavity detuning, RF noise and beam current fluctuations, are simulated. They provide more complete information about the ring beams under high current and high power.

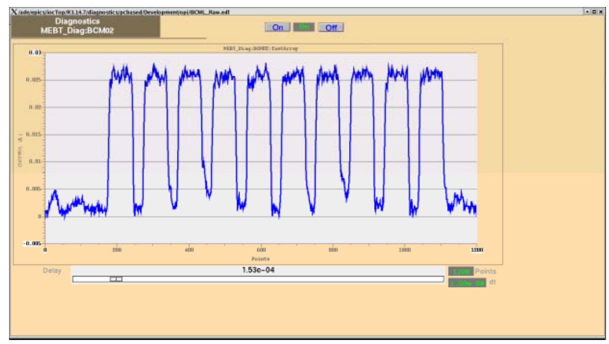

Figure 1: Beam in gap resulting from LEBT chopper problems, measured with a linac beam current monitor.

Beam distribution in the gap is difficult to quantify precisely because it changes from gap to gap and from pulse to pulse. Figure 1 shows a beam current monitor measurement. To simplify the solution, beam is assumed to be uniformly extended up to 25% into the gap. Figure 2 shows a simulation result for beam distribution in the longitudinal space immediately after the accumulation turns. Beam loss in the ring and in the RTBT is not acceptable as a large amount of beam contaminates the extraction gap (outside the two vertical green lines).

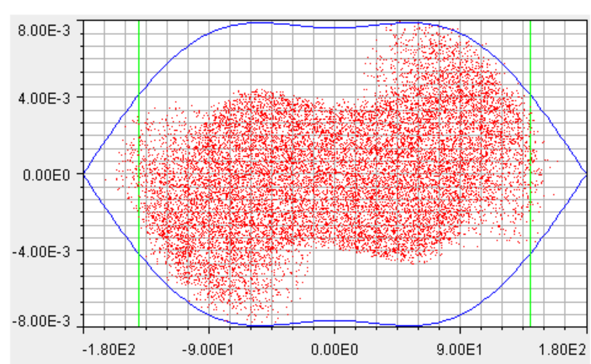

Figure 2: Beam longitudinal space distributions (red dots) immediately after the accumulation, in simulation.

SIMULATIONS

In the simulations, 1 million particles are used for each case, as the study is trying to optimize the ring RF

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#jdg@ornl.gov

systems for a beam loss level of 10^{-4}. Different RF settings and different beam injection turns are compared. Figure 3 shows that for the neutron production of 600 beam injection (or accumulation) turns and the dual harmonic ring RF, the best number of extra beam storage turns is approximately 200.

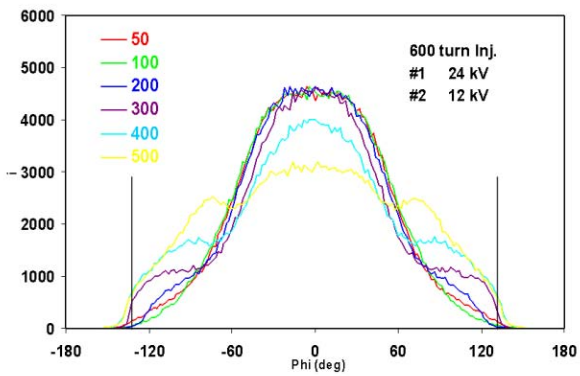

Figure 3: For 600 injection turns and dual harmonic RF, 200 extra beam storage turns minimize beam in the gap.

Figures 4 and 5 show that for single harmonic RF and 450 beam injection turns, the optimum number of extra storage turns is from 200 to 400, mainly depending on the RF voltage.

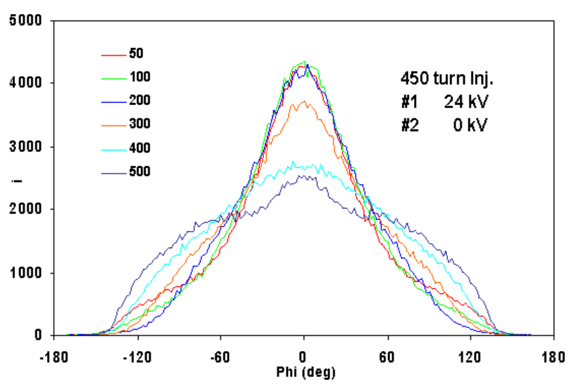

Figure 4: For 450 injection turns with single RF voltage 24 kV, the optimum number of extra storage turns is 200.

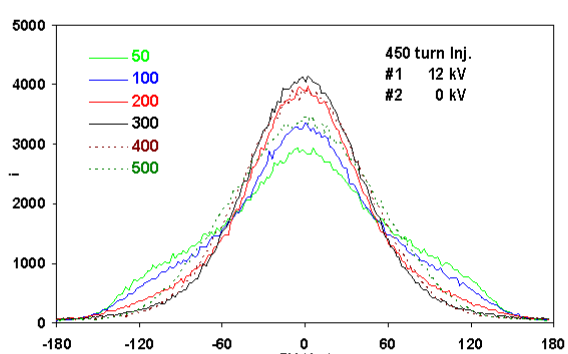

Figure 5: For 450 injection turns with single RF voltage 12 kV, the optimum number of extra storage turns is 400.

In the simulations, beam in gap caused by the LEBT choppers could be cleaned up significantly with the ring dual harmonic RF system and additional beam storage turns after the accumulation turns; but here it serves only as a fast, temporary solution to allow the routine neutron production to resume. Fully functional linac choppers and the design ring RF features are the best solution, and should be pursued in future operation. Appropriate extra storage turns can be utilized to store more beam charge in the ring for a given ion source current and clean extraction gap length [2]. Figure 6 compares numbers of extra storage turns for several chopper leakage cases with the nominal design – no chopper leakage. Dual-harmonic ring RF with an additional 200 storage turns after the beam accumulation turns results in a large improvement in the production, as beam in the gap is reduced by one order of magnitude compared with single RF; beam loss and activation would be decreased significantly, although still slightly worse than in the nominal design.

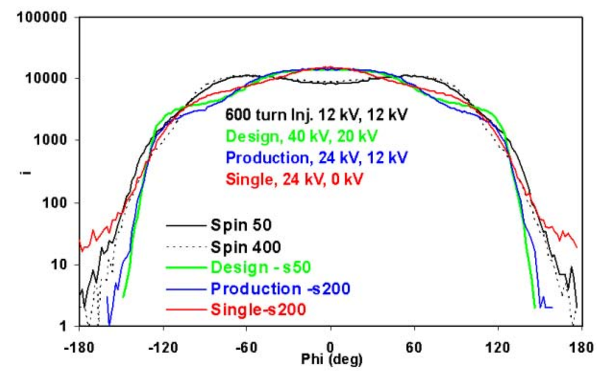

Figure 6: Comparison of single RF and dual harmonic RF with beam bunch leakages, and the nominal ring design.

MEASUREMENTS

The beam current monitor (BCM) in the ring and all beam loss monitors (BLMs) in the ring extraction areas and the RTBT line are used in the measurements. The agreement between the beam bunch shape measured with the ring BCM and the simulation result is not good (Figure 7), perhaps because of RF errors and because the injection beams are not uniformly distributed. However, beam loss measurement agrees with the simulation result.

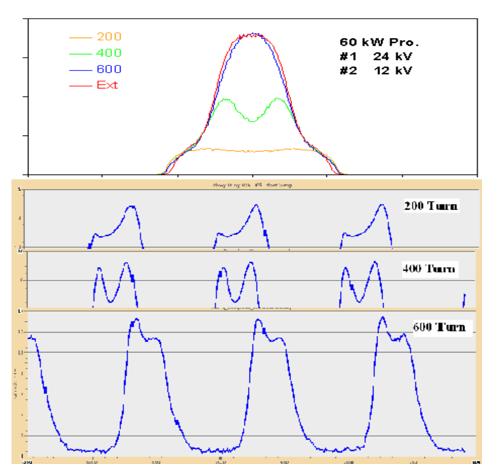

Figure 7: Beam bunch shape in the simulations and in the measurements of 60 kW neutron productions.

For a single harmonic with RF voltage of approximately 12 kV, the optimum number of extra storage turns is around 400, based on the simulations; in measurements based on the ring and the RTBT BLMs, the optimum number is 300–420 for different injection beam conditions and using different BLM weights. Simulation results suggested that for 60 kW production beams with the second harmonic RF station turned on, beam loss in the ring and the RTBT will be reduced by an order of magnitude; we observed this beam loss reduction in the SNS accelerator systems (Figures 8 and 9). It is good agreement, considering the difficulty in obtaining a precise model for an actual total fractional beam loss on the order of 1×10^{-4}.

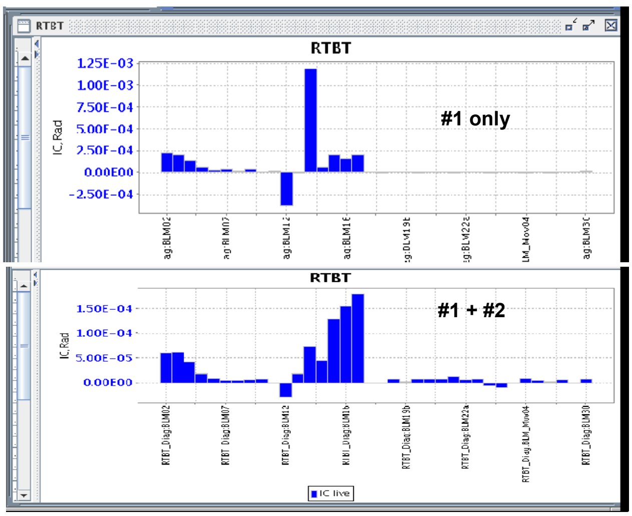

Figure 8: Beam loss in the RTBT beam line is reduced by turning on the second harmonic RF station.

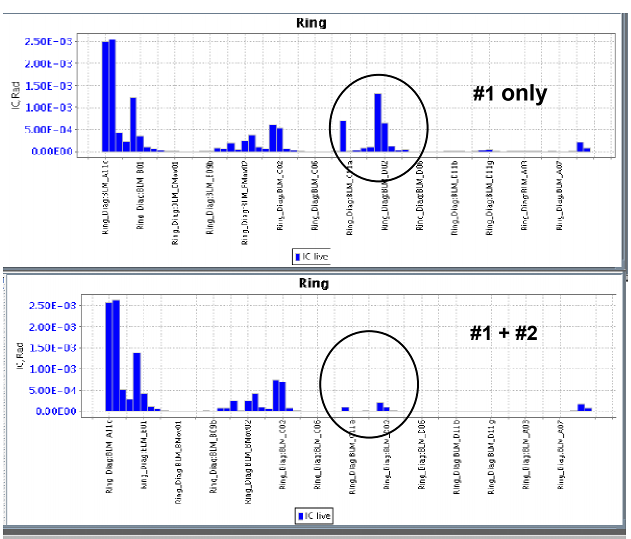

Figure 9: Beam loss in the ring extraction areas is reduced by the second harmonic RF.

In recent neutron production, the problem of the rise/fall time of the LEBT choppers has been fixed and no significant beam bunch leakage is observed in the ring. Therefore, it is not necessary to apply the extra storage turns because beam loss and activation in the RTBT beam line and in the ring extraction areas are small or mainly caused by other mechanisms. As has been mentioned, fixing the rise/fall time of the linac choppers and pursuing the design features of the dual harmonic RF systems are the best solution for reducing the beam loss and activation in the ring extraction areas and in the RTBT line.

However, accurately varying the beam gap width with the linac choppers in each pulse and using appropriate extra beam storage turns in the ring after the accumulation turns will be a helpful method of increasing beam power in the ring, in addition to being the fast, temporary solution for beam loss reduction discussed in this paper. In simulations with the ORBIT code, an increase of up to 20% of the proton beam power in the ring could be expected with this proposed technique. Alternatively, the peak source current could be reduced approximately 15% with a similar decrease in the chopped fraction with the appropriate additional storage turns for gap cleaning to achieve the same beam power to the mercury target [2]. Thus the technique of using extra beam storage turns will become more important to the future SNS power ramp-up plan, and may alleviate ion source requirements. Further beam studies will be performed once the new features have been implemented in the control systems of the linac beam choppers.

CONCLUSIONS

Beam loss and beam activation in the accumulation ring extraction areas and the RTBT beam lines caused by beam bunch leakage into the extraction gap can be significantly reduced with the ring dual harmonic RF and extra beam storage turns after the necessary beam accumulation turns. Measured beam losses in the SNS accelerator systems show close agreements with the model predictions. Extra beam storage turns in the accumulation ring with the ring RF cleanup beams in the gap may provide an important technique for increasing the beam power of the SNS facility. Further study is necessary to achieve this end. The design ring RF features and fully functional linac beam choppers remain the best means of beam loss reduction.

ACKNOWLEDGMENTS

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