SNS RING OPERATIONAL EXPERIENCE AND POWER RAMP UP STATUS*

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Abstract

The SNS Ring has now been operating for about 3.5 years, and our march continues to increase the beam power to the full design value of 1.4 MW. The Ring is a loss-limited machine, and in general the radioactivation levels are good, but there are some unanticipated hot spots that we are working to improve. High intensity collective effects such as space-charge and beam instability have had minimal impact on beam operations to date. The cross plane coupling issue in the ring to target beam transport line has been solved. We will also discuss the status of equipment upgrades in the high-energy beam transport beam line, the injection-dump beam transport line, the ring, and the ring-to-target beam transport line.

INTRODUCTION

Ring commissioning began in January 2006, and formal operation of the SNS as a neutron production facility began in October 2006 with a beam power of 5 kW. Since that time we have steadily increased the beam power to ~850 kW on target. The main issues we face at high beam power are stripper foil lifetime, beam loss / activation, space charge effects, and beam instabilities. In addition we have the usual mix of issues that new facilities typically face, such as correcting equipment issues needed to improve operations and beam availability, and identifying and correcting the beam transport and ring lattice optics.

Stripper foil lifetimes to date have been very good. We typically use just two foils in a four month run cycle. However, this could quickly change as we further increase the beam power. We are continuing to develop our diamond foil technology and explore other foil technologies, such as hybrid boron carbon foils [1].

The beam loss and activation issues in the Ring are primarily in the ring injection area. Activation levels in the vicinity of the stripper foil are high but within the expected range [2]. There is one unexpected hot spot, 10 m downstream of the stripper foil, caused by a combination of foil scattering and circulating beam loss. This loss is being addressed by particle tracking simulations and machine tuning to minimize the loss. The total beam loss in the ring is a few parts in 10^4.

The beam instability that we are most concerned with is the e-p instability. High intensity machine studies have shown that this instability is in fact present in the SNS Ring, but initial measurements [3] show that it is probably not strong enough to cause beam loss during normal operations.

Other than some relatively minor equipment upgrades to improve beam availability, the main equipment issue to date has been with the momentum beam dump system. This system, located in the linac to Ring transport beam line (HEBT), is used to strip high and low momentum tails from the beam. It has been removed from service due to unexpected radiolysis issues, and a new beam dump design is now in progress [4].

Beam transport and ring optics issues to date have been with the ring injection and injection dump beam lines (primarily due to a discrepancy in the chicane magnet specification vs. as-delivered magnetic fields) [5], correction of the ring quadrupole set points [6], and cross-plane coupling in the ring to target beam transport (RTBT) beam line.

In the remainder of this paper we will discuss in more detail space charge effects, cross plane coupling, and the status of our present and future upgrade plans.

SPACE CHARGE EFFECTS

The nominal operating point of the SNS ring is Q_x = 6.23, Q_y = 6.20. This allows the space charge tune shift to avoid the most serious multipole resonances while keeping the coherent tune shift above the integer resonance. At the full design power of 1.4 MW (1.5×10^{14} protons per pulse at 1 GeV and 60 Hz), the incoherent space charge tune shift is expected to be $\Delta Qsc = 0.15$, and the "effective" tune shift (that must be kept clear of resonances) is expected to be 0.09 [7]. The space charge tune shift scales with beam energy according to $N/\beta^2\gamma^3$, and the highest production beam intensity to date is 850 kW (9.4×10^{13} ppp and 928 MeV), so the highest production-intensity tune shift to date is 73% of the full power tune shift. Under these conditions the beam losses are good. The maximum charge stored in the ring to date is 1.3×10^{14} ppp, and the beam energy at that time was 845 MeV. The corresponding tune shift is 19% *greater* than the full power design case. The beam losses for this case were high, but this was a short duration test and we did not have the opportunity to carefully tune the machine to minimize the loss, so it is difficult to draw a firm conclusion about space charge induced beam loss at the full design power beam intensity.

Beam profile measurements at high and low beam intensities have also been measured. A typical result for three different beam intensities is shown in Fig. 1. The normal neutron production transverse painting was used, and the beam intensity was varied by decimating the number of injected turns. The data show hollow profiles at low intensity that fill in as the intensity is increased. This is in qualitatively good agreement with benchmark simulations that are now in progress [8]. These simulations, using the ORBIT particle tracking code, include details such as nonlinear tracking, foil scattering,

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2.5D transverse + 1D longitudinal space charge, longitudinal impedance (but no transverse kicker impedance), and Ring buncher RF.

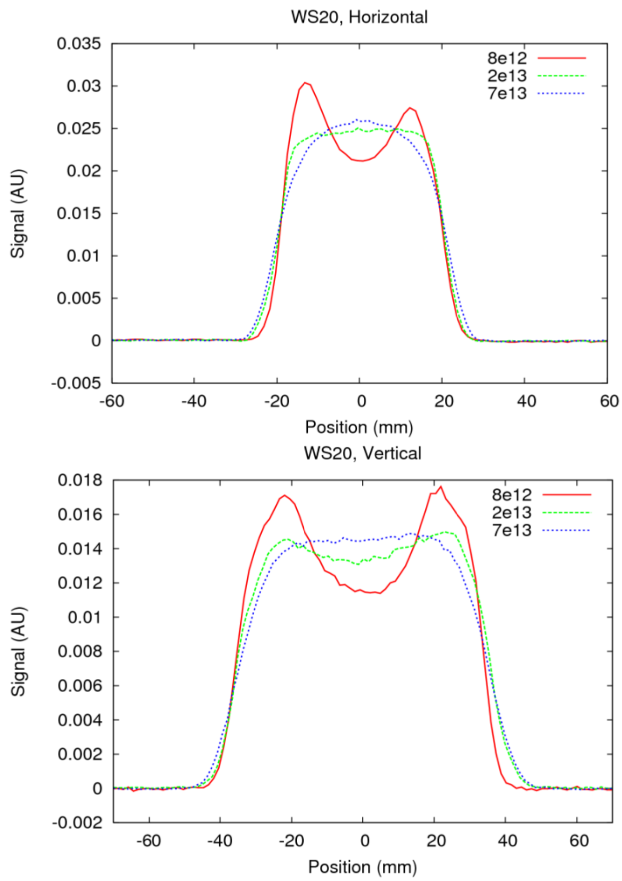

Fig. 1 (color). Beam profiles at a wire scanner in the RTBT beam line, for three different beam intensities (8×10^{12}, 2×10^{13}, and 7×10^{13} protons per pulse). Horizontal (top) and vertical (bottom). The profile amplitudes have been normalized to the area under the curves.

CROSS PLANE COUPLING

In the initial days of beam commissioning we noticed a slightly tilted beam distribution on the target [5,9] Later measurements showed sometimes unusual beam profiles in the Ring to Target beam line (RTBT), and motion in the opposite (horizontal) plane when the vertically deflecting Ring extraction kickers were varied. A new technique was developed [10] to reconstruct real-space beam distributions by injecting a single minipulses in the ring and varying the storage time. This technique effectively allows any BPM in the extraction beam line to be used to generate real-space beam distributions similar to a view screen measurement. Using this method we narrowed down the source of the cross plane coupling to a large skew quadrupole component in the extraction Lambertson septum magnet.

The 3-D magnetic fields of this magnet were then modeled [11] and the resultant predicted fields were used in particle tracking simulations that accurately reproduced the measurements. This same model was then used [11] to determine that the skew quadrupole component could be greatly reduced by simply replacing the pole tip shims in this magnet. The shims were replaced in February 2009, and the cross-plane coupling has now been reduced to below measurable values. Example real-space beam distributions using the single-minipulse reconstruction technique are shown in Fig. 2 for the before and after shim replacement cases. The tilted beam distribution that is evident before the shim replacement is gone after the shim replacement.

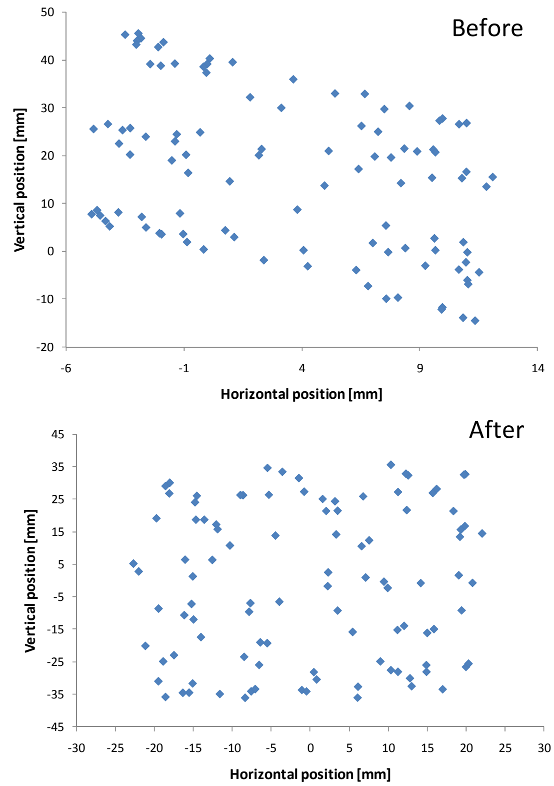

Fig. 2. Real space beam distribution at a BPM in the RTBT, using the single minipulse reconstruction technique, before and after the extraction septum magnet shim replacement. Top: before, bottom: after.

RING AREA UPGRADES

Upgrades that are now in progress in the ring area include replacements for the primary and secondary foil changing mechanisms, a view screen beam profile / position system for the neutron production target, a new momentum dump (mentioned earlier), and an aperture increase in the injection dump beam line.

The primary stripper foil mechanism is being redesigned to allow more rapid foil changes (since this is a high radiation area) and to improve the mechanical reliability and functionality of the mechanism. Our target date for installation is January 2010.

The secondary foil mechanism is being redesigned to increase the stripper foil width, improve the view port to allow the wider foil to be seen, and to include an air lock to allow the foil to be changed without letting the entire region up to air pressure. The target date for this installation is August 2009.

The neutron production target view screen system is based on impregnating the stainless steel outer surface of the neutron production target with Al_2O_3:Cr. This effectively makes the target into a view screen, and the light will be observed using a mirror and rad-hard fiber-optic bundle to transmit the image to a camera located outside the bulk shielding.

The aperture increase in the injection dump beam line is to relieve an aperture restriction that is causing excessive beam loss. This beam line is complex since it transports two beams – the H^- beam that misses the primary stripper foil, and the partially stripped H^0 beam. These two beamlets take different paths to the dump since until they pass through the secondary stripper foil, only the H^- beamlet is affected by the magnetic fields. Also the injection dump septum magnet is a gradient magnet with two different gradients, hence each beamlet sees a different horizontally-focusing field, and so the Twiss parameters of the two beamlets are different, especially downstream of this septum magnet.

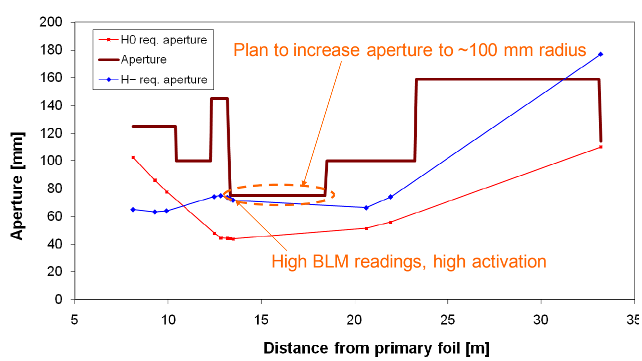

Fig. 3 (color). Beam aperture requirement as a function of distance along the injection dump beam line. Red line: H^0 beamlet, blue line: H^- beamlet, brown line: existing aperture.

The aperture requirements of the beamlets are a combination of their beam sizes and positions. Fig. 3 shows the beam position added to 5 times the rms beam size, as a function of distance along the beam line, for each beamlet. Also shown in this figure are the existing apertures along the beam line. It is clear that the H^- beam encroaches on the available aperture starting about 13 m downstream of the primary stripper foil. Radioactivation measurements at this point also indicate high beam loss. The main reason for the small-aperture in this portion of the beam line is a 150-mm-diameter fast vacuum valve, which at the time was the largest fast valve available. It is now possible to purchase 200-mm-diameter fast valves, and so our plan is to increase the aperture of this ~7 m long portion of beam line from 150-mm diameter to 200 mm. In addition to replacing the fast valve, we will also replace the BPM nearby the quadrupole magnet, and add an additional BPM to improve our ability to steer the beamlets to the center of the beam dump.

FUTURE WORK

Other upgrades that are planned but not yet started include a view screen for the injection dump beam line, and improved beam diagnostics and beam steering in the ring extraction area. The injection dump view screen will be based on the neutron production target view screen system. The vacuum window just upstream of the dump will be Al_2O_3:Cr doped to emit light, which will be viewed from a view port located in the Ring tunnel about 10 m upstream. This will remedy a deficiency in the injection dump beam line: the lack of a direct beam position and profile measurement at the beam dump. These parameters are very important to the proper operation of the beam dump, which is designed to accept up to 150 kW of beam power. Nominal operation calls for sending 5% of the linac beam power to the dump, and as we continue our beam power ramp up to 1.4 MW the importance of correctly positioning and focusing the two beamlets will only increase.

The ring extraction upgrade will improve our ability to properly launch the extracted beam into the ring-to-target (RTBT) beam line. In the existing set up, the first quadrupole magnet in the RTBT beam line is intentionally offset to allow it to also function as a dipole corrector. Also, the first BPM after the extraction kickers is located 27 m downstream of the extraction septum magnet, which makes it laborious and difficult to optimize the extraction kicker set points. In the upgrade we will remedy these shortcomings by installing a BPM just upstream of the septum magnet, a dipole corrector and BPM just upstream of the first quadrupole magnet in the RTBT, and a third BPM 90 degrees phase advance downstream of the new dipole corrector.

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