SNS RING COMMISSIONING RESULTS*

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Abstract

The Spallation Neutron Source (SNS) [1] comprises a 1.5-MW, 60-Hz, 1-GeV linac, an accumulator ring, associated beam lines, and a spallation neutron target. Construction began in 1999 and the project is on track to be completed in June 2006. By September 2005 the facility was commissioned through the end of the superconducting linac, and in January 2006 commissioning began on the High Energy Beam Transport beam line, the accumulator ring, and the Ring to Target Beam Transport beam line up to the Extraction Beam Dump. On April 28, beam was delivered to the spallation target for the first time. In this paper we will discuss early results from ring commissioning.

INTRODUCTION

On January 12, 2006 we received permission to deliver beam to the High Energy Beam Transport (HEBT), Ring, and first part of the Ring to Target Beam Transport (RTBT) up to the extraction beam dump. By the 13th we had beam to the injection dump, by the 14th we had a single minipulse (one 700 ns bunch) circulating for a few turns around the ring, by the 15th we had a single minipulse circulating for more than 1000 turns, and by the 16th we had beam all the way to the extraction beam dump. As the injection kicker and buncher systems were brought on line we were able to increase the beam intensity, and on January 26th we exceeded our initial goal of 10^{13} protons per pulse (ppp) by delivering 1.26×10^{13} ppp to the extraction dump. On February 11 we increased the bunched beam intensity to 5×10^{13} ppp, limited by beam loading in the Ring buncher systems (the buncher systems were only partially commissioned at this time), and on February 12 we achieved our highest-to-date intensity of 1×10^{14} ppp of unbunched beam (i.e. no minipulse chopping and the ring RF turned off), limited by the ion source current and the linac RF pulse length. On February 13 the Ring commissioning period was declared to be complete.

On April 28 we received permission to deliver beam to the spallation target, and later that day, at 14:08, we delivered the first beam to the target. About 90 minutes later we reached our commissioning goal of 10^{13} ppp by delivering 1.6×10^{13} ppp to the target. At the end of May we delivered 4.7 kW (1.6×10^{13} ppp at 2 Hz) to the target

for 95 hours. The beam was then shut off for the month of June for maintenance, and operations will resume in July.

INITIAL RESULTS

Prior to commissioning, the beam diagnostics, magnet polarities, magnet alignment, power supplies, control system, on-line model, etc. were thoroughly checked. Tuning algorithms were also checked using ORBIT [2] simulations. We attribute the rapid success in commissioning the ring and transport lines to this preparatory work. After setting the HEBT magnets to nominal values, the beam arrived at the primary stripper foil on the first shot. More than 1000 turns of single minipulse circulation were achieved without correcting the closed orbit. After energizing the extraction kickers for the first time with beam, only an adjustment to the extraction septum magnet was needed to deliver the beam to the extraction beam dump. The power supplies for the six ring quadrupole families had to be adjusted by 1% to 5% away from modeled design values to achieve the nominal betatron tune. A beam current monitor signal showing a single minipulse in the extraction beam dump transport line, from the first day that this was achieved, is shown in Fig. 1. A closed orbit in the ring, after correction using a model-based method, is shown in Fig. 2, and an example of beam accumulation followed by extraction is shown in Fig. 3. In the remainder of this paper we shall discuss two issues that arose during commissioning followed by preliminary beam instability measurements.
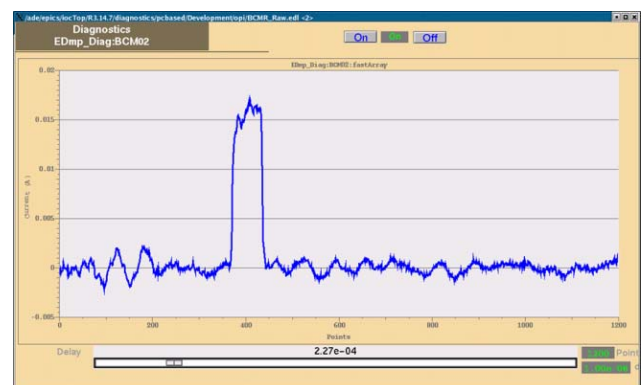

Fig. 1. Beam current monitor in the extraction beam dump line from the first day of beam to the dump.

BEAM ON TARGET

The nominal beam profile at the spallation target is such that 90% of the beam is contained within a rectangle 20 cm wide and 7 cm tall, with the peak density below specified limits. When beam was first delivered to the

target we noticed that the beam was tilted by about 7 deg., which is undesirable since a tilt will tend to raise the peak density (for a given rectangular aperture). The tilt of the image can be empirically removed by adjusting the skew quadrupole correctors in the ring, as shown in Fig. 4.
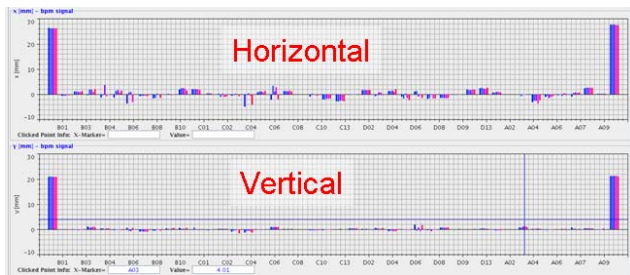

Fig. 2. Example of closed orbit in the ring. The large position excursions at the left and right edges of the plot are due to the injection kickers upstream and downstream of these BPMs. For both plots the vertical axis runs from -10 to +30 mm.
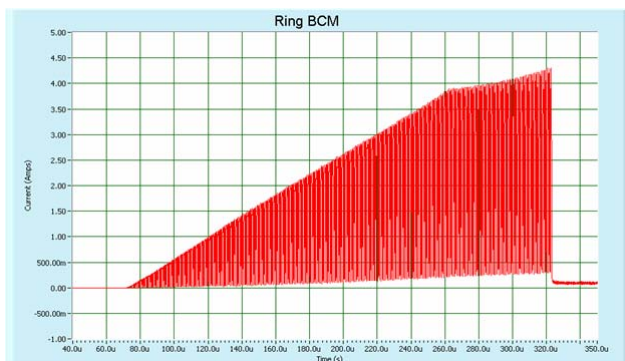

Fig. 3. Ring beam current monitor data for 180 turn accumulation plus about 60 turns storage of 1.6×10^{13} ppp.

The most likely explanation for the tilt is transverse coupling in the ring. We know the ring is coupled, as shown by the turn-by-turn BPM data in Fig. 5. This data was obtained by injecting a single minipulse onto the horizontal axis of the ring and adjusting the vertical injection to be about 30 mm off axis (this is equivalent to a vertical kick of a stored beam). With the skew quadrupole correctors turned off the amplitude of the betatron oscillations in the horizontal plane varies between 1 and 17 mm. By adjusting a few of the 28 skew quadrupole correctors we were able to reduce the amplitude of the horizontal betatron oscillations to 3.5 mm, but this particular set of skew quadrupole set points did not result in an improvement in the tilt of the beam at the target. During the next beam run we plan to systematically adjust the skew quadrupole correctors to cancel both the local and global coupling.

It is important to quickly solve the problem of tilted beam at the target since the temporary view screen provides our best measurement of the beam profile at the target, and it is scheduled to be removed in August. The closest permanent diagnostic is a harp located 9 m upstream of the target
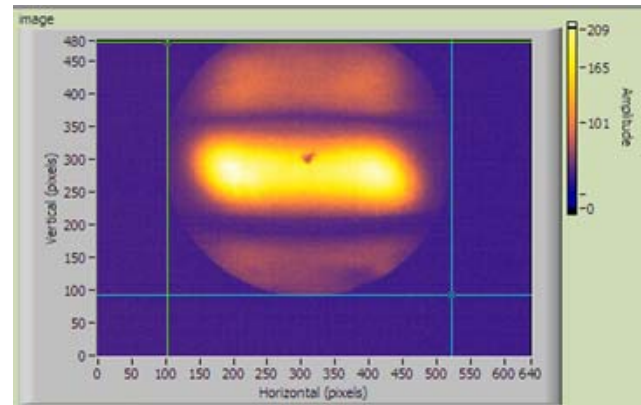

Fig. 4. An image of the beam on target, from a temporary view screen mounted to the face of the target.
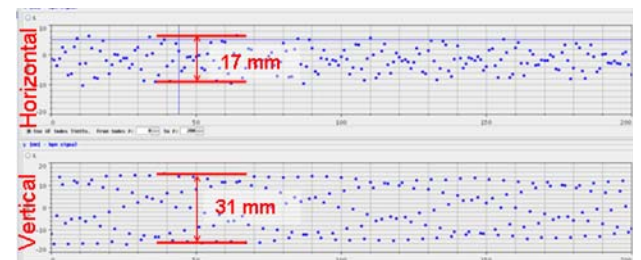

Fig. 5. Turn-by-turn betatron oscillations for a single minipulse injected on axis in the horizontal plane and off axis in the vertical plane. At this BPM $\beta_x \approx 12.4$ m and $\beta_y \approx 2.2$ m.

BEAM LOSS

Beam loss is expected to be a significant issue for the SNS, and it will likely be a limiting factor during high power operations. During the recent 4.7 kW run several high-beam-loss locations were revealed that exceeded our loss specification even though the beam power was only a fraction of the design intensity. The locations are in the beginning of the HEBT, upstream of the collimators; in the injection dump beam line; and in the ring extraction section. Fig. 6 shows the loss monitor display for the ring beam loss monitors during the 4.7 kW run.

The likely source of the beam loss in the HEBT is poor transverse matching in the linac, and from the linac to the HEBT. Prior to this run the laser profile monitor system was out of service and we were unable to properly match the beam in the linac. Several wire scanners in the HEBT had also not yet been installed. These systems will be on line for the next run and we expect these losses to significantly improve when the beam is properly matched in the linac and HEBT.

The beam loss in the injection dump line is due to inefficient transmission of the waste beams (H$^-$ beam that misses the stripper foil and partially stripped H^0 beam). The poor transmission is an unintended consequence of late-in-the-installation-stage change in the position of the stripper foil within the fringe field of the injection chicane magnet (the change was necessary to properly funnel the stripped electrons to the electron collector). For the

immediate future we will install a wider secondary stripper foil, which will allow us to change the injection steering in a way that will improve the waste beam trajectories. The long-term solution may involve replacing a vacuum chamber or two, but this is still under investigation.

The beam loss at the extraction septum magnet is a result of beam in the gap, caused by the 2.5 MeV chopper, which was off-line during the 4.7 kW run. For our next run we expect that this chopper will be back on line, and that the changes mentioned above will result in significantly lower beam losses.
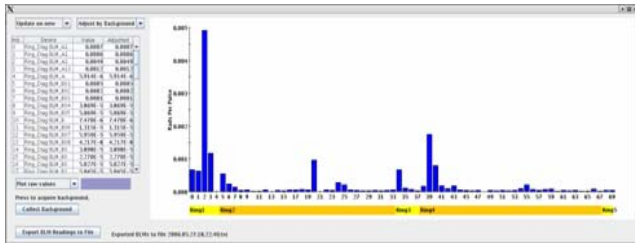

Fig. 6. Beam loss monitors in the ring. The vertical scale is from 0 to 0.005 rads/pulse. The two highest peaks correspond to losses in the injection dump beam line and in the extraction area of the ring.

BEAM INSTABILITIES

One of the biggest uncertainties in high power operation of the SNS ring is the threshold of the e-p instability, since it is difficult to confidently predict. Early in the ring commissioning period we set up the ring to create conditions most favorable for the onset of instabilities – an unbunched, un-extracted coasting beam with near-zero chromaticity that filled the ring circumference (although the bunchers were turned off, the rf buncher cavities were not shorted, and there may have been some longitudinal structure imposed on the beam due to beam excitation of the cavities). Under these conditions, at the nominal betatron tunes $Q_y = 6.23$, $Q_y = 6.20$, we observed [3] two instabilities. Under certain conditions both instabilities can occur in the same shot, as shown in Fig. 7.

The first instability, observed at 3, 6, and 12 μC beam charge and after storing the beam for several milliseconds, is consistent with an impedance-driven instability due to the extraction kickers. The measured growth rate and frequency spectrum is consistent with our expectations and the threshold is high enough that it should not interfere with full power 1.4 MW operations under nominal conditions.

The second instability, observed at 4, 8, and 16 μC beam charge, and again after storing the beam for several milliseconds, is consistent with an e-p instability. Although the threshold for nominal operating conditions cannot be directly extrapolated from these measurements, based on similar measurements at PSR [4] we believe that

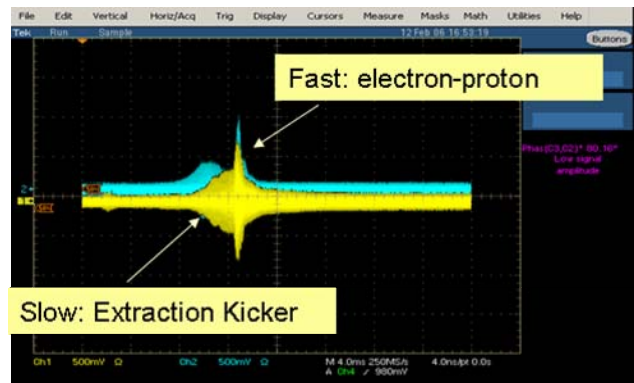it is unlikely that this instability will interfere with full power operations.

Fig. 7. Horizontal and vertical oscillations observed after storing the beam for several milliseconds. Two different instabilities are simultaneously present for this shot.

We observed a third instability after lowering the betatron tune to slightly below the integer ($Q_y \approx Q_y \approx 5.8$) to create conditions favorable for the resistive wall instability. The frequency of this instability is about 191 kHz, as expected, with a growth rate consistent with previous estimates of the impedance of the injection kickers together with the vacuum pipes. As with the other two instabilities, we do not expect this one to interfere with normal operations.

No instabilities have been observed thus far under the more normal condition of bunched beam in the ring, and initial indications are that any instabilities under normal conditions will have thresholds high enough that they will not interfere with full-power 1.4 MW operations.

SUMMARY

The ring commissioning and beam-to-target commissioning was accomplished very quickly and very successfully. Initial indications are that beam instability thresholds are high enough that they will not interfere with normal operations. Although the issues of waste beam delivery to the injection dump and tilted beam at the target were unexpected, we believe the solutions are straightforward and readily attainable.

REFERENCES

[1] N. Holtkamp, Proc. PAC 2003, p. 11.
[2] J. Galambos, J. Holmes, D. Olsen, A. Luccio, and J. Beebe-Wang, ORBIT Users Manual, http://www.sns.gov/APGroup/Codes/Codes.htm.
[3] V.V. Danilov et al., Proc. ICFA-HB2006 Workshop, May 29 – June 2, 2006, Tsukuba, Japan.
[4] R. Macek et al., PAC 2003, p. 3089.