THE COMMISSIONING PLAN FOR THE SPALLATION NEUTRON SOURCE RING AND TRANSPORT LINES*

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Abstract

The Spallation Neutron Source (SNS) accelerator systems will provide a 1 GeV, 1.44 MW proton beam to a liquid mercury target for neutron production. In order to satisfy the accelerator systems' portion of the Critical Decision 4 (CD-4) commissioning goal (which marks the completion of the construction phase of the project), a beam pulse with intensity greater than $1\text{x}10^{13}$ protons must be accumulated in the ring, extracted in a single turn and delivered to the target. A commissioning plan has been formulated for bringing into operation and establishing nominal operating conditions for the various ring and transport line subsystems as well as for establishing beam conditions and parameters which meet the commissioning goal.

INTRODUCTION

The SNS accelerator complex [1] consists of a 2.5 MeV H^- injector, a 1 GeV linear accelerator, an accumulator ring [2] and associated beam transport lines [3]. The ring and transport line layout is shown in Figure 1. The SNS baseline parameters are summarized in Table 1. The H^- beam from the linac is transported to the ring in the High Energy Beam Transport (HEBT) line. Before the 90 degree bend in the HEBT is a tuning beam dump (the Linac Dump) which will be used for linac commissioning and linac tuneup during operations. The HEBT delivers the beam to the stripping foil for charge-exchange injection into the accumulator ring [4]. Unstripped H^- and partially stripped (H^0) beams are fully stripped in a second foil and transported to the injection dump via the injection dump line [5]. In baseline operation, beam is accumulated in the ring over 1060 turns reaching an intensity of $1.5\text{x}10^{14}$ protons per pulse. When accumulation is complete the extraction kicker fires during the 250 nsec gap to remove the accumulated beam in a single turn and direct it into the Ring to Target Beam Transport (RTBT) line, which takes the beam to the liquid-mercury target. Located midway along the RTBT is another tuning beam dump (the Extraction Dump). Both the Extraction and Linac dumps have 7.5 kW beam power capability while the Injection Dump has 200 kW capability.

The commissioning of the accelerator complex will be accomplished in stages as the requisite hardware is delivered and installed on the SNS site. The staged commissioning is already underway with completion of Front-End commissioning [6] in January 2003. After completion of linac commissioning in late 2004, the accumulator ring and transport lines will be commissioned in two separate runs. In the first run, from December 2004 to June 2005, the HEBT, accumulator ring and RTBT to the extraction dump will be commissioned. In the second commissioning run, in December 2005, the remainder of the RTBT is commissioned and beam is delivered for target and instrument commissioning.

The completion of the construction and commissioning

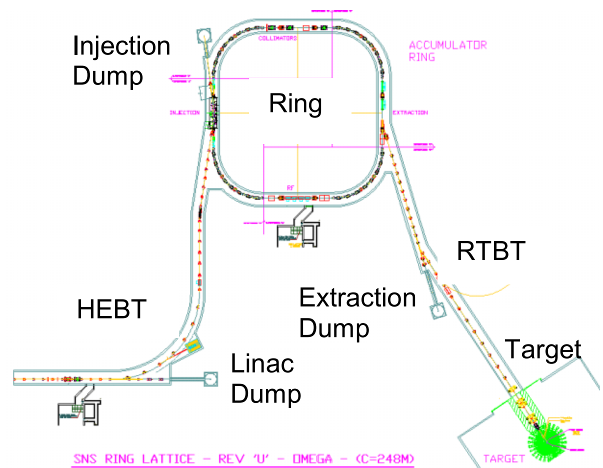

Figure 1: SNS Ring and Transport Line layout

phase of the project is accomplished by demonstrating specific performance criteria. The goal for ring commissioning is to demonstrate the accelerator portion of these criteria (the so-called Critical Decision 4, or CD-4, criteria) which include accumulating, extracting in a single turn and delivering to the target a beam pulse of 10^{13} protons at 1 GeV in a machine configuration capable of 1 MW operation. This CD-4 intensity is more than an order of magnitude less than the design intensity of the SNS, corresponding to 100 kW beam power if delivered at 60 Hz repetition rate.

Table 1: SNS Baseline Parameters

Beam Energy	1 GeV
Ring Beam Intensity	$1.5\text{x}10^{14}$
Repetition Rate	60 Hz
Accumulated Turns	1060
Accumulation Time	1.0 msec
Beam Power on Target	1.44 MW

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In the target commissioning phase the average beam power must be limited to 3-4 kW in order to maintain radionuclide inventory less than the threshold for a Category 3 Nuclear Facility. Thus, administrative limitations are in place to maintain low average power on the target, although higher-power beams may be delivered over a short duration.

A plan has been formulated for commissioning the ring and transport lines to reach the CD-4 goal and beyond. Central to the success of this plan will be the successful commissioning of key diagnostic systems deployed in the transport lines and accumulator ring [7]. The capabilities of those diagnostic systems that will be most heavily relied-upon during commissioning, the beam position monitors (BPM), beam current monitors (BCM), loss monitors (BLM) and wire scanners are summarized in Table 2.

Table 2: SNS Ring and Transport Line Diagnostics

System	**Range**	**Accuracy/ Resolution**
BPM-phase (HEBT)	±180°	±2° / 0.1°
BPM-position	± pipe radius	± 1%/0.5% of radius
BCM (HEBT)	15-52 mA	±1%/0.5%
BCM (Ring/RTBT)	15mA-100A	±1%/0.5%
BLM	1-2.5x10^5 r/hr	±1%/0.5 r/hr
Wire Scanners	± pipe radius	10%/5% on rms width

COMMISSIONING APPROACH

In order to minimize activation of the ring and transport line hardware during commissioning, initial tuning will be performed with a short beam pulse delivered at low repetition rate, typically in a single-shot, "pulse-on-demand" basis. It is expected that linac beam pulse-lengths (controlled by the chopper system in the Front-End injector) in the range 5-20 μsec will be utilized initially, although experience during linac commissioning will provide guidance on the minimum reliably achievable pulse length. The beam intensity can be reduced, if needed, by tuning the ion source, or inserting a current-limiting aperture in the injector beamline.

It is assumed that only the BLMs are functioning on "day-one" as the other systems will need beam to "time-in" and verify proper operation. Initial beam transport in a new section of the ring and transport lines proceeds by tracking the progress with beam loss monitors and minimizing the losses using corrector dipoles. In each case the initial goal is to transport the beam to the appropriate beam dump as rapidly as possible. Once this is accomplished, the basic diagnostics (BCMs, BPMs and profile measuring devices) are commissioned. The transport efficiency is tuned up with BCMs and BLMs. With the beam safely transported to the dump, measurement and correction of the trajectory is performed and beam optics studies and correction commence.

COMMISSIONING SEQUENCE

The following describes the various steps in the commissioning sequence.

HEBT Commissioning

As part of linac commissioning, that portion of the HEBT from the end of the superconducting linac to the Linac Dump is commissioned. A four-wire-scanner array is located in this part of the beamline, allowing measurement of emittance and twiss parameters of the linac output. Several quadrupoles are available for matching the linac beam to the HEBT optics. Proper beamsize at the linac dump window [8] must be verified and adjusted with dump line quadrupoles if necessary. The operability of the dump and bulk shielding are verified up to the beam dump limit of 7.5 kW.

The goals of HEBT commissioning are to bring the HEBT beamline components into operation, commission diagnostics systems, transport a beam to the injection dump and verify the dump's performance, measure and correct the HEBT trajectory and optics and transport a CD-4 pulse (10^{13} protons) to the injection dump. Initial tuning will rely on loss monitors with the goal of transporting the beam to the injection dump, which includes transport through the injection region of the ring lattice. Provision has been made for moving a phosphor screen into place at the injection point (replacing the stripping foil) for visual confirmation of beam parameters.

A number of measurement and correction steps are required to establish proper optical parameters. Achromaticity of the 90 degree bend must be established. Matching of the beam after the achromat to the remainder of the line will be performed using a four-wire-scanner array. The dispersion at the injection point will be measured and corrected if necessary. Finally, two RF cavities, an energy corrector cavity and a momentum painting ("spreader") cavity will be commissioned and their phase and amplitude setpoints established. Once the transport line trajectory and optical parameters have been established, the beam pulse length is increased to transport 10^{13} protons to the Injection Dump.

Ring Commissioning

The objective of this phase of commissioning is to bring the ring hardware into operation, commission key diagnostic systems, measure and correct the ring orbit and optical functions, commission the extraction system, demonstrate accumulation of 10^{13} protons and successfully transport a CD-4 beam to the extraction dump.

The initial commissioning studies focus on transporting a low-intensity beam around the ring to establish the closed-orbit. Initial injection proceeds by powering the dynamic injection bump magnets to place and hold the closed-orbit in the foil while injecting a short pulse of a few ring turns. Initial tuning uses the dipole correctors while observing the beamloss monitors to establish first one, and then several ring turns. The ring BCM is commissioned first and used to tune-up the transport efficiency. The BPM system is then commissioned and the orbit is measured and corrected. Several closed-orbit correction schemes are envisioned: i) harmonic correction, ii) model-based correction, iii) response-matrix (model-independent) correction and iv) three-bump correction. The chicane and injection bump closure is established.

With the trajectory corrected the optics are measured and corrected. The betatron tunes are measured with the turn-by-turn BPM system, the tune controls are commissioned and the tunes adjusted as necessary. By injecting a beam off-axis and observing the betatron motion on the turn-by-turn BPM system the phase advance between BPMs can be measured. This data will then be used in a model-based correction method to adjust the six main quadrupole power supplies to reproduce the design optics. The chromaticity is measured and the sextupoles are powered to commission the chromaticity correction controls. The dispersion is readily measured by injecting an off-energy beam.

Nominal operating conditions of the RF system are then established. The revolution frequency is measured with a wall current monitor. The cavities are independently powered, and the phase and amplitude loop stability is checked with beam. Cavity relative phase setpoints may be found by injecting an “un-chopped” beam with a single cavity powered. The relative phases of the second and third cavities are adjusted to obtain the same WCM profile as observed on the first cavity. The cavity voltages can be set by observing the synchrotron motion of a beam stored for several msec.

The ring extraction system and RTBT to the extraction dump are then commissioned. Proper operation of the individual extraction kicker modules is confirmed by triggering the kickers individually and observing the betatron motion in the ring. The relative timing of the kicker modules is established. A small beam is extracted and the extraction septum aperture is scanned to establish nominal kicker strengths. Extracted beam is first observed on BLMs and a BCM located in the RTBT. A small beam current is transported to the extraction dump. The extraction efficiency and beam transport efficiency in the RTBT is tuned-up with dipole correctors and loss monitors. The bulk shielding of the dump is verified.

In the next phase of commissioning conditions are established for multi-turn injection by phase-space painting with a goal of transporting 10^{13} protons to the extraction dump. This can be achieved by accumulating 70 turns at the nominal ion source current. The injected beam parameters are characterized (momentum spread, energy jijtter and momentum deviation) and then the injected beam controls (position and angle on the foil) are established. The injection kicker waveforms for phase-space painting are loaded and bump closure is measured and corrected. Pulses of successively greater length are injected to reach the 10^{13} goal with minimization of losses by orbit, tune, chromaticity, injection kicker and extraction tuning. The painted beam profiles are measured with monitors in the RTBT and extraction dump line. If necessary, the settings of the primary collimator may be explored at this point of commissioning.

As each portion of the accelerator is commissioned, the beamloss monitor thresholds (used for input to the Machine Protection System, or MPS) are adjusted, and the MPS performance is checked with intentional controlled loss near each location. Fault studies directed at verifying the bulk shielding are performed as outlined in the SNS Operations Procedures Manual.

Studies for High Intensity Operation

After successful accumulation and extraction of 10^{13} protons, studies related to high-intensity and high-power operation of the ring are planned as time permits. A number of accelerator physics issues central to operation at high-intensity can be studied by accumulating beam intensities above the CD-4 goal at low repetition rate. The topics studied will include i) RF system beam-loading compensation, ii) space-charge studies, iii) exploration of unstable collective modes by delaying extraction, iv) measurement of electron-cloud effects and observation of electron signals on electron detectors, and v) test of a prototype transverse feedback system.

RTBT to Target Commissioning

In this final phase of commissioning, the beamline downstream of the RTBT dipole magnet to the target is commissioned, the proper beamsize demanded by the target is verified with a Harp located just downstream of the last quadrupole magnet, and beam pulses of 10^{13} protons are delivered to the target to satisfy the CD-4 goal.

CONCLUSIONS

A detailed step-by-step plan for commissioning the SNS ring and transport lines has been formulated. This plan focuses on achieving the CD-4 criteria of accumulating, extracting in a single turn and transporting to the target 10^{13} protons at 1 GeV.

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