SNS BEAM COMMISSIONING STATUS*

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Abstract

The Spallation Neutron Source accelerator systems will provide a 1 GeV, 1.44 MW proton beam to a mercury target for neutron production. The staged beam commissioning of the accelerator complex is proceeding as component installation progresses. In three separate beam commissioning runs, the H- injector and Drift Tube Linac tanks 1-3 have been commissioned at ORNL. Several important performance goals have been achieved, in particular, demonstration of design 38 mA peak beam current, 1 msec long beam pulse, and 1 mA average beam current. Results and status of the beam commissioning program are presented.

INTRODUCTION

The Spallation Neutron Source accelerator complex [1] will provide a 1 GeV, 1.44 MW proton beam to a liquid mercury target for neutron production. The accelerator complex consists of an H- injector [2] capable of producing 38 mA peak current, a 1 GeV linear accelerator [3], an accumulator ring and associated transport lines [4]. The linear accelerator consists of a Drift Tube Linac (DTL), a Coupled-Cavity Linac (CCL) and a Superconducting Linac (SCL). The baseline linac beam has a 1 msec pulse length, 38 mA peak current, is chopped with 68% chopper-on duty and repetition rate of 60 Hz to produce 1.6 mA average current.

The staged beam commissioning of the accelerator complex is proceeding as component installation progresses. At this point, the H^- injector and Drift Tube Linac tanks 1-3 have been commissioned at ORNL. A summary of baseline design parameters and beam commissioning results is shown in Table 1.

FRONT-END PERFORMANCE AND COMMISSIONING RESULTS

The Front-End Systems were designed and built by Lawrence Berkeley National Laboratory (LBNL), commissioned at LBNL in May 2002, and reassembled and recommissioned at ORNL in late 2002. The results of that commissioning run have been reported previously [2]. The Front-End consists of an H- ion source, an electrostatic low-energy beam transport (LEBT) line, a 2.5 MeV, 402.5 MHz RFQ, and a Medium Energy Beam Transport (MEBT) line in which the beam is matched transversely and longitudinally into the DTL. Included in the MEBT are Beam Position Monitors (BPMs), Beam Current Monitors (BCMs) and wire scanners.

Nearly 5 months of commissioning and operations time have been accumulated on the SNS Front-End Systems. The Front-End injector was operated at high-duty factor to provide beam for a high-power run which is discussed below. Recently, an improved understanding of the MEBT optics has been demonstrated. Figure 1 shows excellent agreement between measured horizontal and vertical beam profiles and those predicted from a model-based fit to the input twiss parameters.

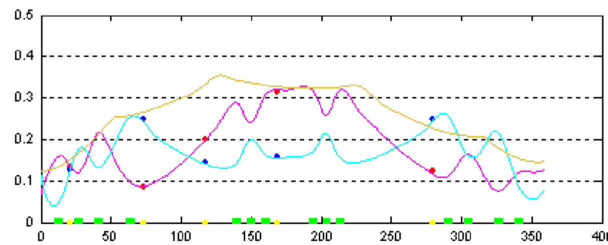

Figure 1: Beam profile (cm) vs. distance in the MEBT (cm). The points show measured horizontal and vertical beam profiles and the curves show the predicted horizontal profile (red), vertical profile (blue) and longitudinal profile (brown).

Additionally, the MEBT output energy was measured by a time-of-flight technique and found to be 2.45 +/- 0.01 MeV, compared with 2.50 MeV nominal design energy.

Numerous improvements implemented on the Front-End, lessons learned from the commissioning runs, and an aggressive R&D program on the ion-source hot spare stand yielded a significant increase of the ion source availability: starting at 85.6%, it increased to 92.4% in the second, and finally 97.8% in the most recent DTL1-3 run.

DRIFT TUBE LINAC TANK 1 PERFORMANCE AND RESULTS

The Drift Tube Linac consists of six accelerating tanks operating at 402.5 MHz with final output energy of 87 MeV. The transverse focusing is arranged in a FFODDO lattice utilizing permanent-magnet quadrupoles. Some empty drift tubes contain beam position monitors and dipole correctors. The intertank sections contain BCMs, wire scanners and energy degrader/faraday cups (ED/FC).

The first three of six DTL tanks have been commissioned with beam in two separate runs. In the first run, DTL tank 1 (with output energy 7.5 MeV) was commissioned into a dedicated Diagnostics System [5] (the "D-plate") equipped with energy degrader/faraday cups, wire scanners, beam position monitors, a slit/harp

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emittance system, and a Bunch-Shape Monitor (BSM) [6], to enable detailed characterization of the output beam parameters, as well as a full-power beamstop for a test of high-power operation.

The goals of the commissioning runs [7] have been to demonstrate full system functionality, demonstrate beam acceleration with design beam parameters to the limits of the available beamstop, test and validate beam commissioning algorithms, and commission the installed diagnostic devices.

The basic procedure for setting the RF phase and amplitude of the DTL tanks relies on the acceptance scan method utilizing the ED/FC located after each tank. The degrader thickness is chosen to absorb beam particles with energy just below the nominal acceptance. The phase and amplitude are determined by comparing the phase profile of the transmitted current with beam dynamics simulations. An example measurement is shown in Figure 2. The derivative of the current provides a measure of the input beam phase width, and is in agreement with MEBT model predictions

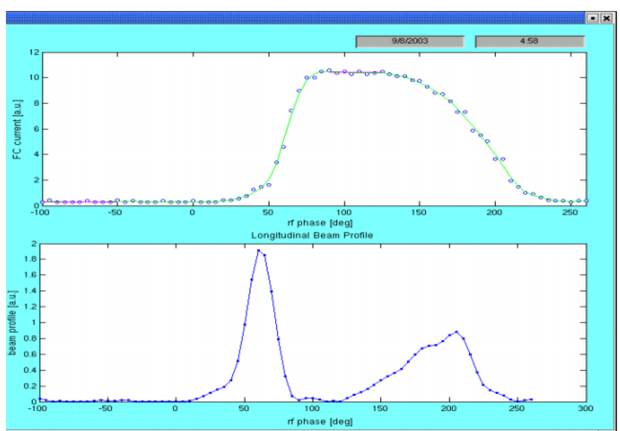

Figure 2: DTL tank 1 acceptance scan. The top curve shows the transmitted current through the degrader measured on the Faraday cup as a function of DTL1 phase. The lower curve is a derivative of the upper curve.

The DTL Tank 1 commissioning results are summarized in Table 1. The design peak current of 38 mA was readily achieved. A 1-msec long beam pulse was generated at 20 mA average current during the pulse (at low duty factor). Finally, a 1 mA average current beam was accelerated in DTL1 with 100% beam transmission. For this demonstration, a beam pulse of 26 mA peak current, 650 microsecond pulse length at 60 Hz (7.6 kW beam power) was achieved. Figure 3 shows an overlay of Beam Current Monitor signals in the MEBT and DTL1 during this high-power demonstration run. This was an important milestone, in that it shows the injector is capable of 1 MW-class SNS operation.

Extensive DTL1 output beam emittance measurements were performed (see also [8,9]) with a slit-collector system. Figure 4 shows a horizontal emittance measurement at 38 mA peak current. The data are analysed in two ways. First, a gaussian fit is performed to

Table 1: SNS design vs. achieved beam parameters

	Baseline Design or Goal	Achieved in Commissioning
MEBT peak current [mA]	38	52
DTL1 peak current [mA]	38	40
DTL1-3 peak current [mA]	38	38
DTL1 beam pulse length [msec]	1.0	1.0
DTL1 average current [mA]	1.6	1.05
DTL1 horiz emittance [π mm mrad (rms,norm)]	0.3	0.30 (fit), 0.40 (RMS)
DTL1 vertical emittance [π mm mrad (rms,norm)]	0.3	0.21 (fit), 0.31 (RMS)
DTL1 beam duty factor	6.0%	3.9%
MEBT Beam Energy [MeV]	2.5	2.45 ± 0.010
DTL2 output energy [MeV]	22.89	22.94 ± 0.11

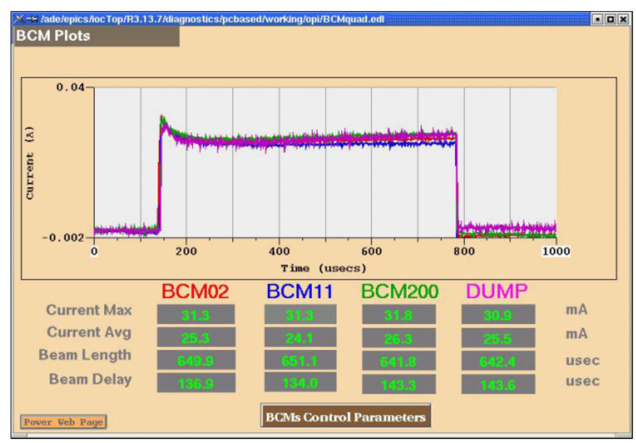

Figure 3: Beam current monitor traces during the DTL1 high-power run. The traces show the beam current after the RFQ (red), after the MEBT (blue), after DLT1 (green) and at the beamstop (purple).

the two-dimensional beam distribution in position-angle space to obtain an emittance that can be considered representative of the beam core. Values obtained in this way are 0.21 π mm mrad (rms, normalized) in the vertical plane and 0.30 π mm mrad in the horizontal plane at 38 mA peak current, both of which achieve the emittance goal. In a second analysis, the RMS of the beam distribution is calculated with a 1% threshold (relative to the peak beam intensity) to remove spurious noise. Values obtained in this way are somewhat larger than the core emittances: 0.31 π mm mrad, and 0.40 π mm mrad in the vertical and horizontal respectively. Further analysis of the large set of emittance data is in process and will be reported in a subsequent publication. A number of systematic effects in the emittance data are being investigated. For example, we see evidence of a large slit-scattering component that produces an opposite-sign signal (since the H- ion is stripped to protons) which reduces the beam signal. Analysis and modelling of slit-scattering and its correction is underway.

A number of measurements pertaining to the longitudinal dynamics were obtained from BSM measurements and will be discussed in a subsequent publication [6].

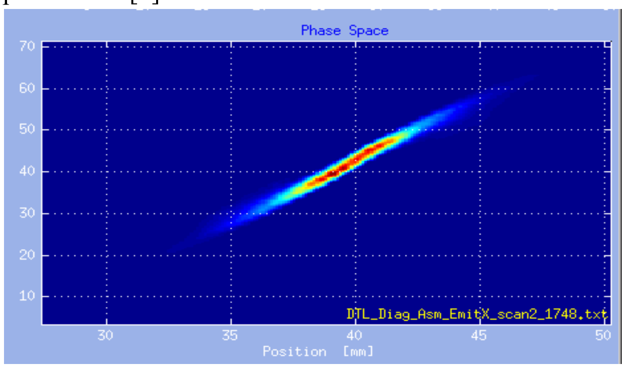

Figure 4: Horizontal output emittance from DTL tank 1 at 38 mA peak current. Angle (mrad) is plotted vs. position (mm).

DRIFT TUBE LINAC TANKS 1-3 PERFORMANCE AND RESULTS

In a third commissioning run, DTL Tanks 1-3, with output energy of 40 MeV, were commissioned into a low-power beam stop. Again, a peak current of 38 mA was readily transported through all three tanks with 100% transmission (within the 2-4% BCM measurement uncertainty). The beamstop limited pulse lengths to less than 50 microseconds, and repetition rates to 1 Hz. It is notable that the trajectory errors with all dipole correctors turned off remains within ±1.5 mm in the MEBT/DTL1-3 system. Correction of the trajectory makes no measurable improvement in beam transmission.

A second technique for determining DTL tank phase and amplitude setpoints, as well as determining the input energy, was explored. In this method, based on the "phase-scan signature matching" approach [10], the beam phase from a single BPM, or the phase difference between two BPMs downstream of a DTL tank are measured as a function of the tank phase and amplitude. Figure 5 shows an example for DTL1, in which three sets of measured phase differences were recorded from BPMs located after DTL tank 1. The data are limited only to those points where more than 7 mA of beam current was transported in order to ensure a reliable beam phase measurement. One scan was taken at nominal RF amplitude, one at 5% above nominal, and the other at 5% below nominal. As is evident in the Figure, the signatures are quite sensitive to the RF amplitude. A model-based fit was then performed to these three phase-scan "signatures" to obtain the RF amplitude, relative phase of beam and RF, and the input energy. Interestingly, the input energy of 2.45 MeV, measured in this way, agrees with that measured by TOF in the MEBT. This is a powerful method that promises to offer more accurate determination of DTL setpoints than the acceptance scan method utilizing an ED/FC.

Time-of-flight measurements were also performed. Using BPMs located in DTL3 with the tank unpowered, a DTL2 output energy of 22.94±0.11 was measured, which agrees with the design value within measurement uncertainty. The energy jitter and long-term drift were also measured. Averaging all data taken during a 30-minute period results in 0.08% rms output energy stability, which corresponds to 0.6 degree phase stability measured on a single BPM.

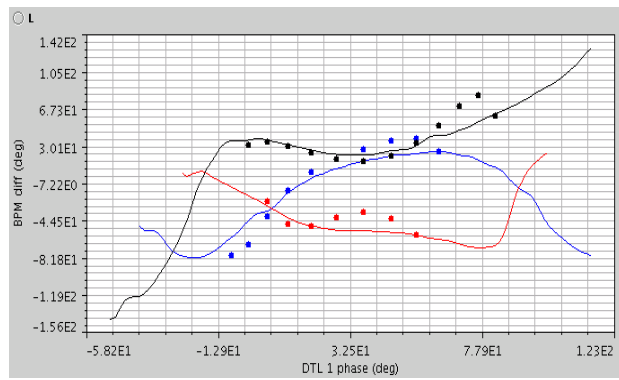

Figure 5: Curves show the measured phase difference (degrees) between two BPMs downstream of DTL1 as functions of DTL1 RF phase for nominal RF amplitude (blue), 5% below nominal (red) and 5% above nominal (black). The points show the result of a model-based fit to the data.

CONCLUSIONS

Commissioning of the SNS linac has been progressing well. Acceleration to 40 MeV of beam pulses with the peak design current of 38 mA has been readily achieved. The Front-End and DTL1 were operated at 1 mA average current. In the next commissioning period in fall 2004 the DTL and CCL modules 1-3 will be commissioned. In spring 2005 CCL-4 and the SCL will be commissioned.

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