SNS WARM LINAC COMMISSIONING RESULTS

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Abstract

The Spallation Neutron Source accelerator systems will deliver a 1.0 GeV, 1.4 MW proton beam to a liquid mercury target for neutron scattering research. The accelerator complex consists of an H - injector, capable of producing one-ms-long pulses at 60 Hz repetition rate with 38 mA peak current, a 1 GeV linear accelerator, an accumulator ring and associated transport lines. The 2.5 MeV beam from the Front End is accelerated to 86 MeV in the Drift Tube Linac, then to 185 MeV in a Coupled-Cavity Linac and finally to 1 GeV in the Superconducting Linac. The staged beam commissioning of the accelerator complex is proceeding as component installation progresses. Current results of the beam commissioning program of the warm linac will be presented including transverse emittance evolution along the linac, longitudinal bunch profile measurements at the beginning and end of the linac, and results of a beam loss study.

INTRODUCTION

The SNS warm linac consists of an H^- injector, capable of producing one-ms-long pulses with 38 mA peak current, chopped with a 68% beam-on duty factor and repetition rate of 60 Hz to produce 1.6 mA average current, a 86 MeV Drift Tube Linac (DTL), 185 MeV Coupled Cavity Linac (CCL), and associated transport lines [1]. At this point, the warm linac has been fully commissioned at average power levels lower than nominal due to limited beam dump capability. The Front End and the first tank of DTL were commissioned at nominal average power. A comparison of major beam design parameters with the parameters achieved during commissioning is shown in Table 1. Results of the initial commissioning can be found in [2]. In this paper we report the latest results of the warm linac performance and resolution of earlier encountered problems.

FRONT-END PERFORMANCE

The front-end for the SNS accelerator systems is a 2.5 MeV injector consisting of the following major subsystems: an RF-driven H^- source, an electrostatic low energy beam transport line (LEBT), a 402.5 MHz RFQ, a medium energy beam transport line (MEBT), a beam chopper system and a suite of diagnostic devices. The front-end is required to produce a 2.5 MeV beam of 38 mA peak current at 6% duty factor. The 1 ms long H^- macro-pulses are chopped at the revolution frequency of the accumulator ring (~1 MHz) into mini-pulses of 645 ns duration with 300 ns gaps. The front-end has been providing beam for commissioning the rest of the linac since the initial commissioning at the SNS site in 2002. All commissioning goals have been achieved and results published in [2]. The Front Systems continue to demonstrate reliable operation with more than 90% beam availability. In the previous runs we commissioned the chopper systems but didn't use them routinely. During the latest run the Front End was required to continuously provide chopped beam for ring operation.

Table 1. SNS achieved vs. design beam parameters.

Parameter	Design	Measured
Peak current [mA]	38	>38
Average current [mA]	1.6	1.05 DTL1 0.004 CCL
H^-/pulse [$x10^{14}$]	1.6	1.3 DTL1 1.0 CCL
Pulse length [msec]/Rep-rate [Hz]/Duty Factor [%]	1.0/60/6	1.0/60/3.8 DTL1 .8/2/.005 CCL
RFQ rms emittance, normalized [π mm mrad]	.21	.22 horizontal .25 vertical
MEBT rms emittance, normalized [π mm mrad]	0.3	< 0.3 horizontal and vertical
DTL rms emittance, normalized [π mm mrad]	0.3	<0.3 horizontal and vertical
CCL rms emittance, normalized [π mm mrad]	0.3	<0.3 horizontal and vertical
MEBT bunch length, rms [degrees of 402.5 MHz]	18.5	18
CCL1 bunch length, rms [degrees of 805 MHz]	3	<4
Max output energy [MeV]	186	186±0.40

Chopper Systems

The 1-ms long H^- macro-pulses must be chopped at the revolution frequency of the accumulator ring into mini-pulses of 645 ns duration with 300 ns gaps. Beam chopping is performed by two separate chopper systems located in the LEBT and MEBT. The last lens in the LEBT is split into four quadrants to allow electrostatic chopping using the RFQ entrance flange as a chopper target. The LEBT chopper removes most of the beam charge during the mini-pulse gaps, and the traveling-wave MEBT chopper further cleans the gap to a level of 10^{-4} and reduces the rise and fall time of the mini-pulse to 10 ns [3]. A chopper controller provides different patterns of chopped beam: "regular chopping", "single mini-pulse", "every n-th mini-pulse", "blanking-off", current ramp up and down. The LEBT chopper demonstrated specified rise and fall time of < 50ns and beam in gap extinction of < 1 % for nominal chopper pattern only. We discovered significant current leakage in the blanking off mode, which is used to cut off the ion source start up transient, create single mini-pulse and decimate mini-pulses in “every n-th mini-pulse” mode. This current leakage does not increase beam in gap in the ring but makes injecting single turn difficult thus complicating beam measurements in the ring. Partially chopped beam could also be responsible for losses in the linac. A single mini-pulse produced by the LEBT chopper alone is shown in Fig. 1 (top), parasitic pulses are observed before and after the mini-pulse. To suppress parasitic pulses we plan to increase the chopping voltage in the next generation of chopper high voltage power supply. We demonstrated that the MEBT chopper also helps in removing parasitic pulses as shown in Fig. 1 (bottom) but it was not ready for routine operation during the last run.

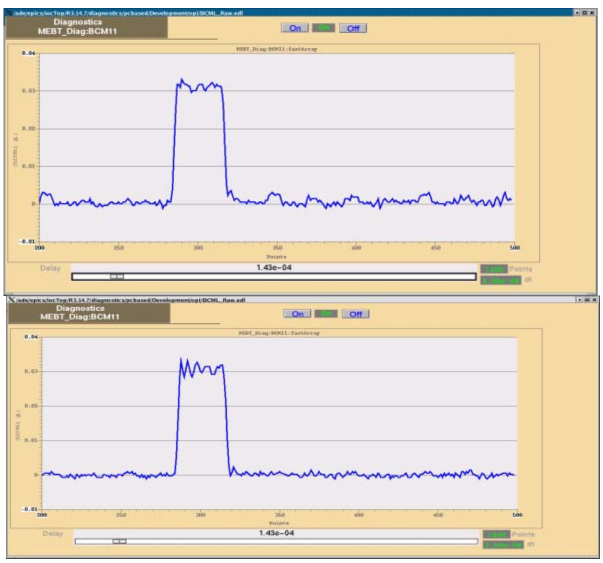

Figure 1. Single 700 ns mini-pulse. Top: produced by the LEBT chopper alone, parasitic pulses observed before and after the pulse. Bottom: MEBT chopper is on, parasitic pulses suppressed.

DTL AND CCL PERFORMANCE

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 BPMs and dipole correctors. The inter-tank sections contain BCMs, wire scanners and energy degrader/faraday cups.

The Coupled Cavity Linac (CCL) consists of four 12-segment accelerating modules operating at 805 MHz with final output energy of 186 MeV. The inter-segment sections contain electromagnet quadrupoles arranged in a FODO focusing lattice, BPMs, wire scanners and Beam Shape Monitors [4].

After testing several algorithms for setting the RF phase and amplitude of the DTL and CCL cavities [2] we chose the so-called “phase-scan signature matching” algorithm as our main tuning procedure [5]. Excellent agreement between measurements and model is observed after eliminating some bugs in the XAL implementation of the algorithm [6] as seen in Fig. 2.

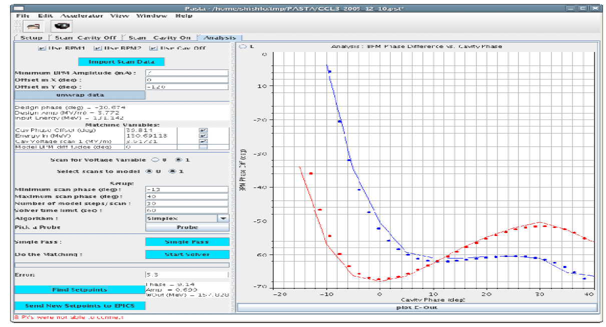

Figure 2. Typical result of CCL cavity phase scan. Solid lines are measured beam phase vs. cavity phase for nominal RF amplitude (blue) and 5% below nominal (red). Points show the result of a model-based fit to the data.

Bunch Length in the CCL

During the previous run we discovered significant discrepancy between expected from simulations and measured bunch length in the first module of the CCL [2]. We attributed that effect to contamination of one of the DTL tanks [7]. We measured bunch length after cleaning the tank and found excellent agreement between measurements and model as seen in Fig. 3.

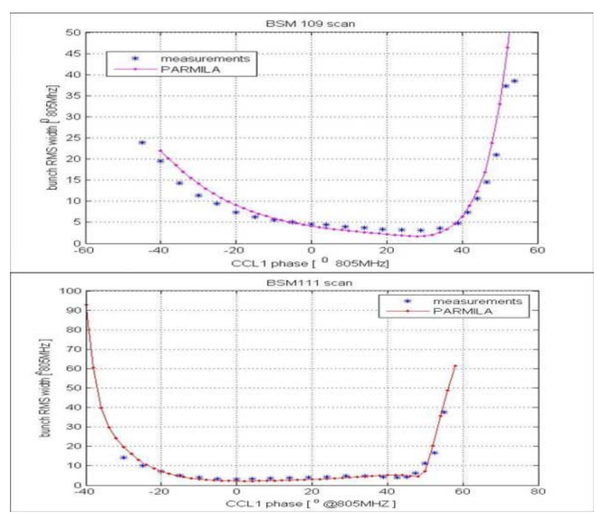

Figure 3. Dependence of the longitudinal bunch size in CCL vs. cavity RF phase. Top: segment #9. Bottom: segment #11. Results of measurements are shown by the asterisks, PARMILA simulations by the solid lines.

Beam Loss in the Warm Linac

There is no reduction in beam current along the linac detectable by the beam current monitors. An overlay of BCM traces at several linac locations is shown in Fig. 4. Beam loss monitors (BLM) based on ionization chambers are used to detect radiation due to beam losses [8]. A typical beam loss distribution in the linac and HEBT measured by BLMs is shown in Fig. 5. Beam loss in the warm linac is low in absolute value and low compared to other parts of the accelerator. The localized peak observed at the very end of the warm linac is due to losses in the transition section between the warm and the cold parts of the linac. The vacuum chamber aperture is kept small there to separate the warm and the cold vacuum systems but the beam size increases to match to a longer focusing period in the SCL. As seen in Fig. 5, losses in that place reduced by factor of ~5 when the beam current was increased from 20 mA to 30 mA. Explanation to this seemingly counterintuitive observation is in the method we use to control beam current. We defocus the beam at the RFQ entrance in order to reduce the current. Emittance of the injected beam and amount of partially chopped beam increase as a result. As soon as beam was properly focused in the LEBT losses in the transition region reduced significantly. This makes transition region losses a good indicator of quality of the injected beam and quality of matching between the MEBT and the DTL. It is also worth noting that space charge induced emittance and halo growth does not create significant losses up to at least 30 mA of peak current

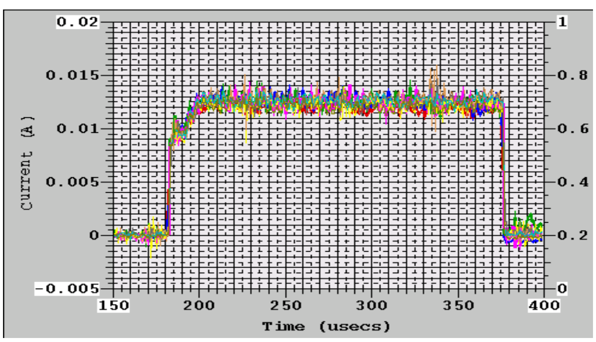

Figure 4. Overlay of beam current monitors traces in the linac for a typical beam pulse.

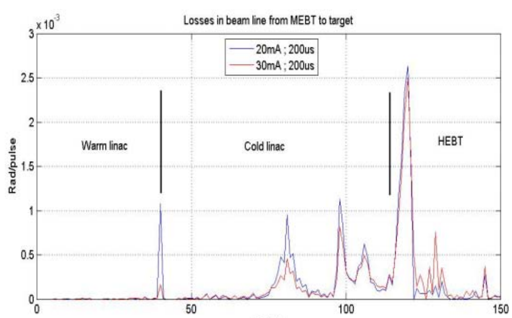

Figure 5. Beam loss distribution along the beam line from the DTL entrance to the HEBT exit during 5 kW production run. Blue line: 20mA peak current;. red line: 30 mA peak current; chopped beam, 200 us pulse at 2 Hz

Resolution and sensitivity of the BLM system is sufficient for observing small beam losses and studying beam matching and space charge effects as shown in Fig. 6. If losses in Fig. 6, which were measured for beam with 30 mA peak current 200 us pulse width scale linearly to nominal beam parameters of 60 Hz, 1 ms; 38 mA then less than 100 rad/hour of prompt radiation will be produced at nominal power, which will satisfy loss requirements.

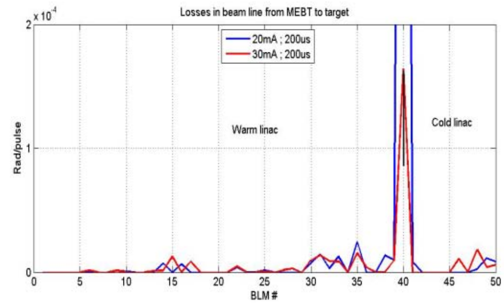

Figure 6. Beam loss distribution along the beam line from the DTL entrance to the SCL entrance. Same beam parameters as in Fig. 5.

CONCLUSIONS

The SNS warm linac has been successfully commissioned. Acceleration to the design energy of 186 MeV of beam pulses with the design peak current of 38 mA has been achieved. The Front End and DTL1 were operated at 1 mA average current. Tuning algorithms are well established and provide stable set points. In general, there is good agreement between the measured beam parameters and the design values. The larger than expected bunch length in the CCL is not observed after cleaning the DTL contamination. Chopper systems were used for ring and target commissioning, and for low power operation. Transmission of partially chopped beam, unacceptable for high power operation, is discovered and being addressed. Beam losses in the warm linac are low and expected to satisfy requirements at nominal beam power. Localized losses observed in the CCL to SCL transition area are found to be caused by intentional beam defocusing in the LEBT when operated at reduced peak current.

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