PERFORMANCE OF SNS FRONT END AND WARM LINAC

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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, and 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. With the completion of beam commissioning, the accelerator complex began operation in June 2006. Injector and warm linac performance results will be presented including transverse emittance evolution along the linac, longitudinal bunch profile measurements at the beginning and end of the linac, and the 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, an 86 MeV Drift Tube Linac (DTL), a 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", and current ramp up and down. The LEBT chopper demonstrated specified rise and fall time of < 50 ns 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-pulses 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 a single turn difficult thus complicating beam measurements in the ring. A single mini-pulse produced by the LEBT chopper alone is shown in Fig. 1 (top), where 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 the chopper high voltage power supply. We demonstrated that the MEBT chopper also helps in removing parasitic pulses as shown in Fig. 1 (bottom). Currently the MEBT chopper is not used in routine operation due to problems with the deflector not holding its rated voltage. The problem is being investigated.

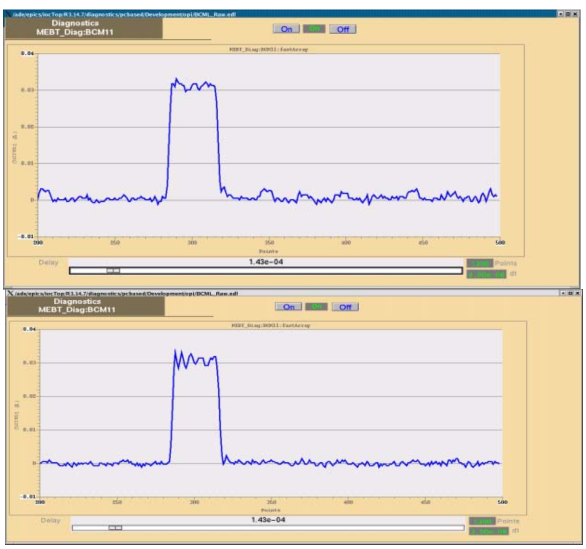

Figure 1: Single 700 ns mini-pulse. Top: produced by the LEBT chopper alone, parasitic pulses observed before and after the pulse. Bottom: MEBT chopper is on, parasitic pulses suppressed.

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].A typical scan result is shown in Fig. 2. The improvement in tuning accuracy led to a significant reduction in beam loss in the SCL and the HEBT transition area as will be discussed below.

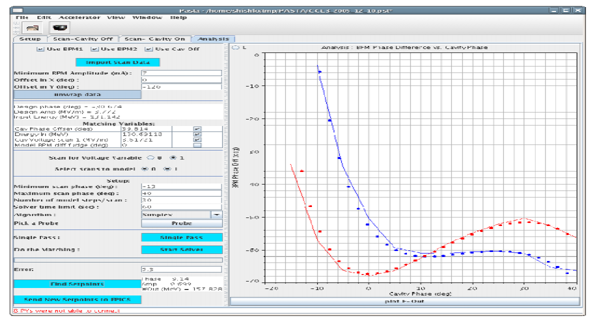

Figure 2: Typical result of CCL cavity phase scan. Solid lines are measured beam phase vs. cavity phase for nominal RF amplitude (blue) and 5% below nominal (red). Points show the result of a model-based fit to the data.

Bunch Length in the CCL

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

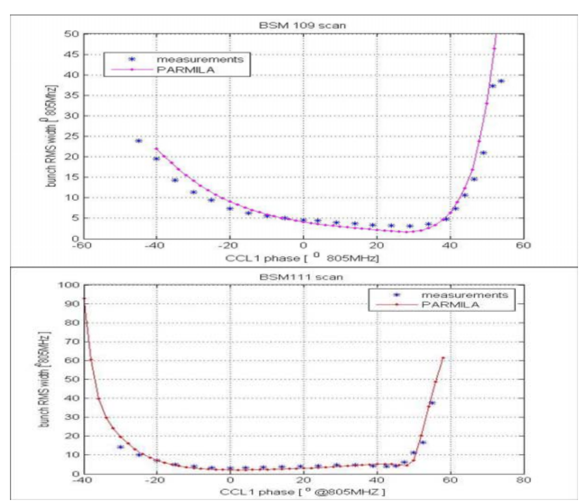

Figure 3: Dependence of the longitudinal bunch size in CCL vs. cavity RF phase. Top: segment #9. Bottom: segment #11. Results of measurements are shown by the asterisks, PARMILA simulations by the solid lines.

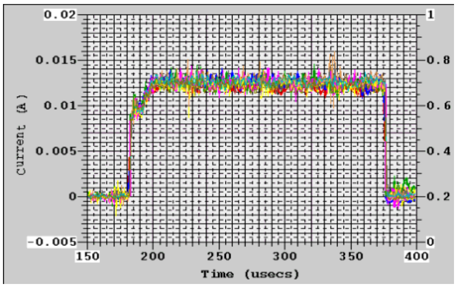

Figure 4: Overlay of beam current monitors traces in the linac for a typical beam pulse.

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 comparison of beam loss distributions in the linac and HEBT measured by BLMs during May 06 Aug 06 runs are shown in Fig. 5. Significant reduction in beam losses was achieved by combination of improved longitudinal tuning of the CCL, mentioned above, and new a scheme of SCL tuning, which keeps longitudinal focusing constant [10]. It proved that puzzling large losses in the SCL and HEBT transition area [9] were caused by longitudinal rather than transverse mismatch. The localized peak was observed at the very end of the warm linac, where the vacuum chamber aperture is reduced to separate the warm and the cold vacuum systems, and the beam size increases to match to a longer focusing period in the SCL. This makes transition region losses a good indicator of quality of the injected beam and quality of matching between the MEBT, the DTL and the CCL. We still haven't done a thorough study of transverse beam matching and using design values for the matching quadrupole magnets strength.

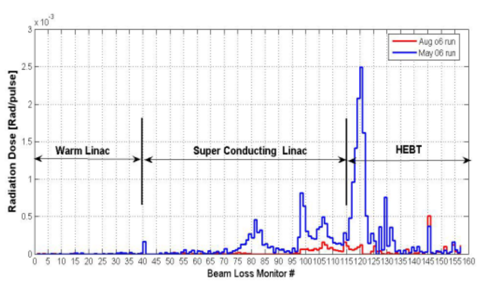

Figure 5: Comparison of beam loss distribution in the linac and the HEBT for two runs. Blue line: May 06; red line; Aug 06. 20 mA peak current; chopped beam, 200 us pulse in both cases.

Beam loss in the warm linac is low in absolute value and expected to be below tolerable level of 1W/m at the nominal beam power shown in Fig. 6 by the blue dashed line. This prediction is based on the assumption that losses scale linearly with beam pulse width, which we have confirmed experimentally up to 500 us, and with beam current. We have verified that space charge induced emittance and halo growth does not increase losses up to at least 30 mA of peak current [9].

The resolution and sensitivity of the BLM system is sufficient for observing small beam losses and studying beam matching and space charge effects.

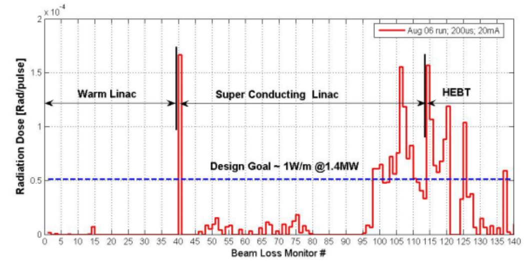

Figure 6: Beam loss distribution along the beam line from the DTL to the HEBT during the latest run. Same beam parameters as in Fig. 5. Dashed blue line shows radiation dose rate corresponding to 1W/m at design beam parameters.

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 lengths in the CCL are 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, was discovered and is being addressed. Beam losses in the warm linac are low and are expected to satisfy requirements at nominal beam power.

ACKNOWLEDGEMENT

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