THE SNS BEAM DIAGNOSTICS EXPERIENCE AND LESSONS LEARNED

A. Aleksandrov
Oak Ridge National Laboratory, Oak Ridge, TN 37830 USA

Abstract

The Spallation Neutron Source accelerator systems are designed to 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 accelerator systems are equipped with a variety of beam diagnostics, which played an important role during beam commissioning. They are used for accelerator tuning and monitoring beam status during production runs. This paper gives an overview of our experience with the major SNS beam diagnostics systems.

INTRODUCTION

The SNS accelerator complex 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 a repetition rate of 60 Hz to produce 1.6 mA average current; an 87 MeV Drift Tube Linac (DTL); a 186 MeV Coupled Cavity Linac (CCL); a 1 GeV Super Conducting Linac (SCL); a 1 GeV Accumulator Ring (AR); and associated transport lines. After completion of the initial beam commissioning at a power level below nominal, the SNS accelerator complex is gradually increasing the operating power with the goal of achieving the design parameters in 2011. Results of the initial commissioning and operation experience can be found in [1]. The SNS Power Upgrade Project (PUP) [2] aims at doubling the beam power by 2016. This will be achieved by increasing the SCL and AR beam energy to 1.3 GeV and the peak current in the linac to 59 mA.

The SNS baseline design included a diverse set of beam diagnostics [3], which, for the most part, were brought on line simultaneously with other accelerator systems and which played an important role in the successful SNS commissioning and power ramp-up. As the SNS operation is shifting more and more toward neutron production for users, the roles and requirements for the beam diagnostics are changing as well. This paper describes the status and development plans for the major beam instrumentation systems.

BASELINE SET OF THE SNS BEAM DIAGNOSTICS

The original set of SNS diagnostics included beam current transformers (BCMs); beam position and phase monitors (BPMs); ionization chambers and photomultiplier tubes (BLMs); wire scanners (WS); slit-and-harp emittance scanners; phosphor view screens (VS); and Faraday cups. All of these devices were operational during the initial beam commissioning and their performance characteristics were sufficient for all of the commissioning tasks.

Beam Current Monitors

There are 23 fast beam current transformers in the SNS linac, ring, and transfer lines. They were useful during the initial commissioning until good beam transmission was established. The accuracy of the BCMs, on the order of 5%, is not sufficient for detecting a typical beam loss of .01%. Several of the BCMs are still in use for beam accounting and for protection purposes in the injector, in front of the beam dumps, and in front of the target. A typical result of the BCM measurements is shown in Figure 1.

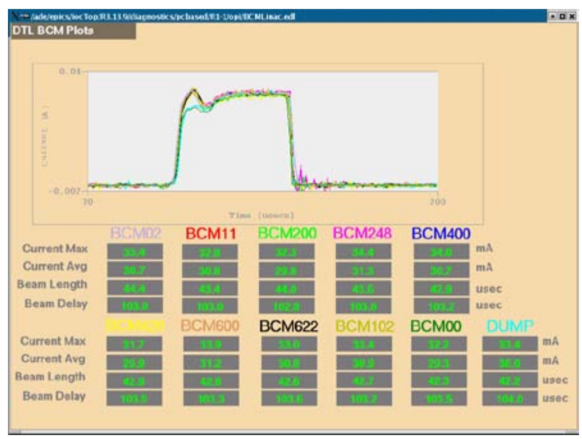

Figure 1. A beam pulse transmission from the injector to the linac beam dump measured by linac Beam Current Monitors.

Beam Loss Monitors

The SNS BLM system consists of 362 detectors measuring the secondary radiation due to beam loss. The BLMs are used as sensors in the machine protection system for shutting off the beam if the integral loss is above a certain threshold. The ionization chamber (IC) is the main detector type in the BLM system due to its simple design and immunity to radiation damage. In addition to the ICs we use several types of photo-multiplier tube based detectors (PMTs). The BLM system has worked quite reliably and typically cause less than ten hours of beam down-time per year. We encountered a few problems with the BLM system during the beam commissioning. The biggest one was significant background from the X-ray radiation produced by the RF cavities. We were able to reduce its effect by implementing a background subtraction scheme, described in [4], but the X-ray background remains the major signal-to-noise limiting factor for the linac BLMs. The other problem was a large number of blind spots in the warm linac due to a strong dependence of the ICs signal on the location of the beam loss. We had to double the number of the ICs in the CCL in order to provide sufficient coverage. The neutron detectors, in contrast, demonstrated a poor ability for localizing the loss point, making them a good sensor for machine protection, but a less suitable device for machine tuning.

Beam Position and Phase Monitors (BPM)

The beam phase monitors are the main tools for the linac tune up which uses Time-Of-Flight algorithms. Position measurements are used for trajectory correction in the linac, ring injection set up and centering of beam on the dumps and target. Both the phase and the position are measured by the BPM system, using 160 4-lobe strip-line pick-ups installed along the beam path. A narrow-band RF front-end electronics is used in the linac and the HEBT. Base-band front-end electronics is used in the ring and the RTBT. The BPM electronics consists of a custom designed PCI board installed in a rack mounted PC running the LabView program under the Windows XPe operating system.

Figure 2. The BPM PCI card inside the PC chassis.

The BPMs demonstrated good performance during the beam commissioning. The design requirements of 0.5° for the phase resolution and 0.5 mm for the position resolution were easily met. The biggest problem with the BPM system is a relatively high frequency of unscheduled PC reboots, which are required to keep the BPMs in an operational state. A typical distribution of the reboot events for a year-long period is shown in Figure 3. We have not been able to trace this problem down to any single hardware component or software bug.

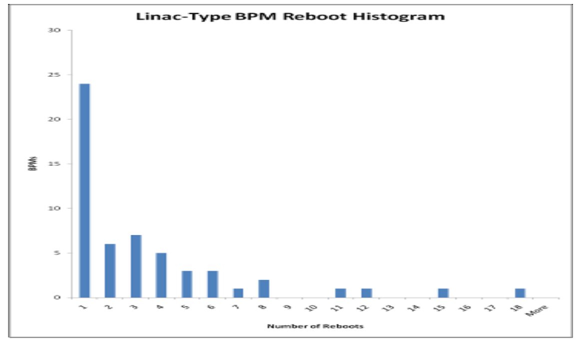

Figure 3. A typical distribution of the SNS linac BPM PC reboots for a year-long period. The number of reboots is on the x axis; the number of the BPMs is on the y axis.

Transverse Beam Profile Measurements

Conventional stepping wire scanners are used for measuring the transverse beam profiles in the normal conducting linac and the transport lines. 32 μm thick carbon wires are used in the warm linac up to 20 MeV; 100 μm thick tungsten wires are used at higher energies. The beam pulse length has to be reduced to 50 μs during the scan. The wire scanners deliver reliable profile measurements with a dynamic range of about 100. This dynamic range has been sufficient for the initial beam commissioning, and the beam core matching during operation, but it is not sufficient for beam halo and loss studies. We found that a cross-talk between the diagonal and the horizontal/vertical wires was the major factor limiting the dynamic range. The dynamic range increased significantly after we removed the diagonal wire and spread the vertical and horizontal wires farther apart. Typical profile scans before and after the modifications are shown in the Figures 4 and 5.

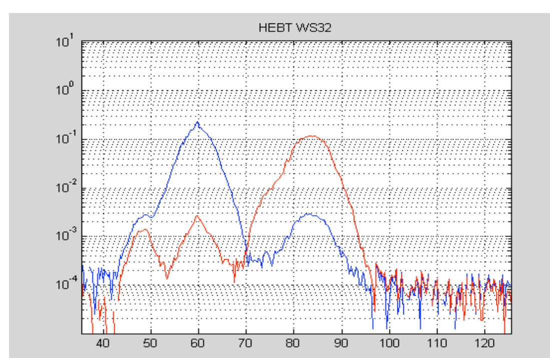

Figure 4. A typical output from the wire scanner before the modification. The vertical profile is in blue; the horizontal profile is in red. The dynamic range is limited to 100 by a cross-talk between the wires.

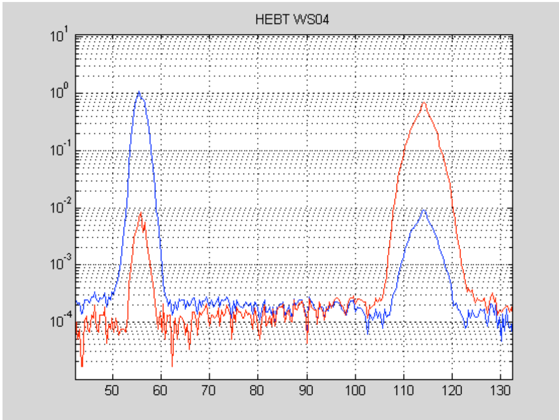

Figure 5. A typical output from the wire scanner after the modification. The vertical profile is in blue; the horizontal profile is in red. The dynamic range increased to about 10000.

A conventional slit/harp device is used for measuring the transverse emittance of the beam in the Medium Energy Beam Transport (MEBT) line. We found these measurements to be very useful for the initial beam commissioning and the acceptance tests of the RFQ and the DTL. Unfortunately, we observed a significant systematic error, up to 20-30%, in the measured emittance value. This problem has not yet been completely resolved. An example of the anomalous measurement is shown in Figure 6 in red. In this experiment the beam divergence was changed by varying the strength of an upstream focusing element. To the first order, the beam emittance should not depend, , on the beam divergence (orientation of the emittance ellipse, in other words), as illustrated by the simulation results shown in blue/green dots on the same plot. The measured emittance value showed a very strong dependence on the divergence, which can only be explained by a systematic measurement error.

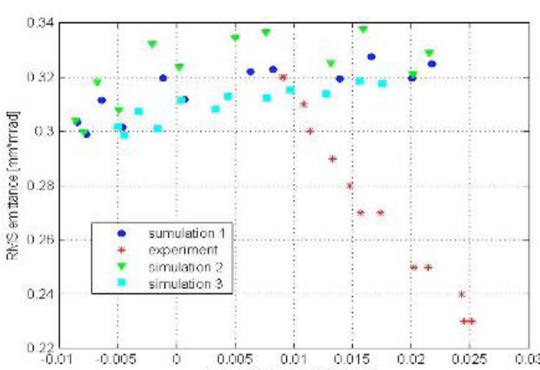

Figure 6. The measured beam emittance vs. the beam divergence (red dots) compared to the expected dependence (blue and green dots). The observed difference is attributed to a systematic error in the emittance measurements.

Longitudinal Beam Profile Measurements

There were several devices for the longitudinal bunch profile measurements available during the beam commissioning: a Laser Bunch Shape Monitor (LBSM) in the MEBT; four Bunch Shape Monitors (BSMs) in the CCL; and two BSMs in the HEBT [5]. Longitudinal bunch size measurements proved to be useful for the linac set up and troubleshooting, and the beam dynamics studies.

The BSMs have a very large dynamics range up to 10^4-10^5, as illustrated by the typical bunch profile measurement shown in Figure 7. Its time resolution of about 2 ps was sufficient for the initial beam commissioning. The resolution needs to be improved by a factor of 2 or more in order to be useful for resolving current beam dynamics issues. The plot in Figure 8 shows an example of a discrepancy between model and measurements on the order of 0.5º @805MHz (or ~1.7 ps), which requires a better resolution measurement to conclude with certainty that the model is incorrect.

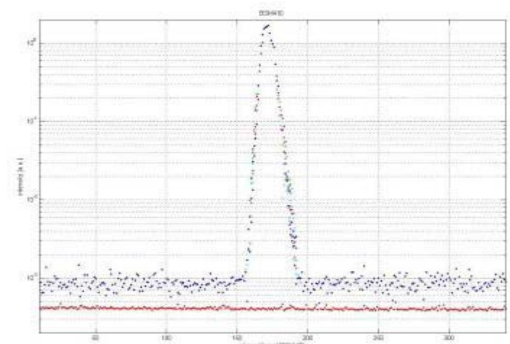

Figure 7. A typical bunch profile measured by the BSM in the SNS warm linac.

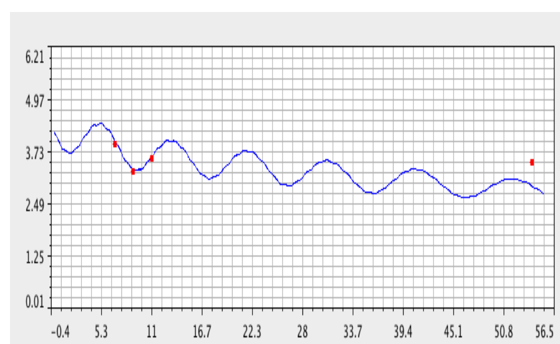

Figure 8. The bunch length along the SNS CCL. Blue line is data from the model, red dots are the BSM measurements.

The LBSM is not operational at the moment because of lack of resources to support it.

LESSONS LEARNED AND FUTURE PLANS

Our experience of a successful and timely commissioning of the SNS accelerator complex has proved, that the base-line set of diagnostics and its performance requirements were well suited for the initial commissioning and power ramp-up. We also learned that the requirements for daily operation and post-commissioning beam study are quite different. To formulate the new requirements we need to distinguish the three main periods within the SNS operational cycle: the neutron production, the tune up for production, and the machine study time.

Neutron production period

The neutron production period currently takes about 80% of the scheduled beam time, and this fraction is steadily increasing. The most important performance metric during this period is beam availability. Therefore only systems directly involved in the beam delivery are important. Beam instrumentation systems connected to the Machine Protection System (MPS) fall in this category. These include the Beam Loss Monitors; the beam-in-gap detector; the Differential Beam Current Monitor, which protects the MEBT chopper target; the beam dump current detectors, which protects the beam dumps from excessive power; and the target power monitor. These systems have to operate at the beam rate of 60Hz. If any of the MPS significant systems fails the beam in the machine is inhibited. Increasing the redundancy is our main approach to increasing reliability of these systems. For example, we are working on the development of a single channel hot-swappable set of electronics for the BLMs to replace the existing multichannel VME based BLM electronics [6].

Machine tune up period

A machine tune up period is required after each maintenances period and currently takes about 10% of the scheduled beam time. If any single or even several diagnostics systems fail during this period, beam operation is still possible. The most important performance metrics during this period are accuracy of the data, ease of use (user friendliness), and speed of taking data. Operators should be able to perform the tune up procedures as quickly as possible, with as little support from diagnostics experts as possible. The main systems for the machine tune up are the Beam Position and Phase Monitors and the Wire Scanners. These systems have to operate at a reduced pulse rate of 1-6 Hz. The BLMs are also used for the fine tuning of the losses. Improving the user interface and increasing the speed of the mechanical devices, such as wire scanners or emittance scanner, is our main focus for these systems. For example, rewriting the software for the MEBT emittance scanner reduced the scan time from 9 min to 4 min.

Machine study period

About 10% of the scheduled beam time is dedicated to the machine study. All available diagnostics can be used during this period. If any single or several diagnostics systems fail, the beam operation is still possible. The most important performance metric during this period is accuracy of the data. Measurements are usually done by physicist, often with help from diagnostics experts. Some of the diagnostics systems for machine study can be of experimental nature or in a prototype stage of development. Beam halo measurements and transverse profile measurements in the ring are examples of such systems. These systems are required to operate at a reduced pulse rate of 1-6Hz. Our main focus in this category of diagnostics is to increase accuracy and dynamic range of beam profile measurements and provide non-interceptive measurements whenever it is possible. Examples of the non-perturbing profile measurements at SNS are the laser wire in the super-conducting linac [7] and the electron beam scanner in the proton ring [8].

ACKNOWLEDGEMENT

ORNL/SNS is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

REFERENCES

[1] S. Henderson, Proc. EPAC 2008, p.2892
[2] S. Henderson et. al., Proc. EPAC 2006, p.345
[3] T. Shea, Proc. DIPAC 2005, pp.6
[4] J. Pogg et al., these proceedings
[5] A. Aleksandrov et. al., Proc. PAC 2007, pp 2608
[6] A. Zhukov et al., Proc. PAC2009
[7] Y. Liu, NIM A 612 (2010), pp. 241–253
[8] W. Blokland et al., Proc. DIPAC2009