RESULTS OF THE SNS FRONT END COMMISSIONING AT BERKELEY LAB[*]

A. Ratti, J.J. Ayers, L. Doolittle, J.B. Greer, R. Keller, S. Lewis, C. Lionberger, M. Monroy,
J. Pruyn, J. W. Staples, D. Syversrud, R. Thomae, and S. Virostek
E. O. Lawrence Berkeley National Laboratory, Berkeley, CA, USA

A. Aleksandrov for the SNS Accelerator Physics Group and T. Shea for the SNS Beam Diagnostics Collaboration
Oak Ridge National Laboratory, Oak Ridge, TN, USA

Abstract

The Front-End Systems (FES) for the Spallation Neutron Source (SNS) project comprise an rf-driven H^- ion source, an electrostatic 2-lens LEBT, a 2.5 MeV RFQ, followed by a 14-quadrupole, 4-rebuncher MEBT including traveling-wave fast choppers. The nominal 2.5 MeV H^- beam has a current of 38 mA at a repetition rate of 60 Hz and 1 ms pulse length, for a macro duty-factor of 6%, and is chopped at a rate of approximately 1 MHz with a mini duty-factor of 68%. The normalised rms beam emittance at the MEBT exit, matching the first tank of a 402.5 MHz Alvarez linac, is measured to be approximately 0.3 π mm mrad. Diagnostic elements include wire scanners, BPMs, fast current monitors, a slit-harp emittance device and RFQ field monitoring probes. The results of the beam commissioning and the operation of the RFQ and diagnostic instrumentation are reported. The entire FES was shut down at LBNL at the end of May 2002 and will be re-commissioned at ORNL prior to installation of the drift-tube linac.

1 INTRODUCTION

The Spallation Neutron Source [1] is being built by a collaboration of six US Laboratories[**] led by Oak Ridge National Laboratory which will operate the facility at their site. The project construction started in 1998, and its completion is expected by 2006.

The collaborative nature of this project is reflected in the initial commissioning activities of the front end (linac injector) at LBNL described here, where members of the Accelerator Physics group at ORNL and the Beam Diagnostics teams from BNL and LANL were contributing hardware, software, and technical support.

The front end was built at LBNL and sequentially tested as the subsystems were completed and installed. Early results obtained at the various stages were reported at previous conferences, starting with the ion source and LEBT commissioning [2] and the RFQ construction [3]. A separate paper at this conference describes the installation of the RFQ and its own commissioning with beam [4, 5] which started in January of 2002 and ended in March.

The 402.5-MHz Low Level RF system is the subject of another paper submitted to this conference [6].

The commissioning phase at LBNL demonstrated all relevant parameters of the front end and supported the decision to ship the equipment to ORNL on schedule in June.

A key part of the commissioning activities was devoted to the beam instrumentation systems that were developed in a collaborative effort by several labs. The wire scanner hardware was built at BNL, while the rest of the beamline devices were built at LBNL. The electronics for the commercial Bergoz current transformers were developed at BNL, and LANL delivered the electronics for the wire scanners. A laser-based beam-profile monitor, although not part of the project baseline, was delivered by BNL and tested on the front end beam [7].

Beam was successfully transported to the end of the MEBT on the first shot on April 4, 2002. The beam measurements described here went on through May 31 when 50 mA were recorded behind the MEBT, see Fig. 1, well in excess of the nominal 38 mA.

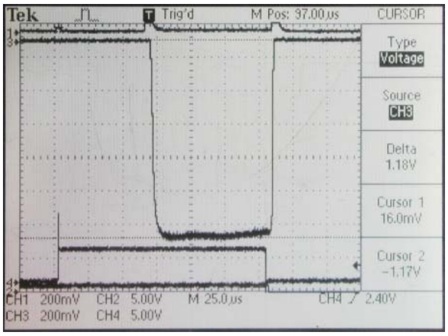

Figure 1. Faraday cup signal of a 50-mA beam transported through the MEBT.

2 BEAM SIMULATIONS

The simulation tools used for space-charge affected beam modelling were TOUTATIS for the RFQ and PARMILA for the MEBT. An actually measured emittance from the LEBT was converted into a 6-dim phase-space

---

[*] This work is supported by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF-00098.

[**] The SNS project is being carried out as a collaboration of six US Lab-oratories: Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Thomas Jefferson National Accelerator Facility (TJNAF), Los Alamos National Laboratory (LANL), E. O. Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Dept. of Energy.

distribution and taken as input file for TOUTATIS. In simulated output-beam spectra as a function of RFQ gradient, low-energy particles were accurately tracked and could later be identified on measured RFQ emittances.

3 DIAGNOSTIC BEAMLINE

A diagnostic beamline consisting of an emittance slit and collector harp was developed for use with the SNS Front End commissioning. This device was used for beam studies at the end of first the RFQ and later the MEBT.

The slit consists of two 13.5” long jaws made from molybdenum TZM and arranged with a total opening angle of 10° and a slit opening of 0.002”. Both jaws are actively cooled with passages machined into back plates that are brazed to either jaw. The slit was designed with the help of a time-resolved ANSYS model that accurately depicts the deposition of heat below the surface of the material. It can handle the full power, 60-Hz, 2.5-MeV beam with a pulse length of up to 50 μs.

The collector is a customised NTG 32-wire harp with 0.5-mm wire spacing. It includes a back plate to suppress secondary electrons. A 32 channel, 2 MS/s, 16 bit commercial data-acquisition board is used to process the signals from the wires and the back plate. Measured dc bias signals were subtracted from the raw data, and slit scattering effects observed with this system as shown in Fig. 2 were subtracted during the final data analysis. All components were fiducialized on a CMM, providing accurate alignment of the slit to the beam and the harp to the slit.

In order to cover the observable phase space, the slit and collector positions are controlled by two separate motors travelling at a fixed speed ratio of 1:7. This resulted in an overall reduction of the number of electronic channels needed for the data acquisition. The motion of these two stages, as well as the data acquisition itself, were fully controlled in the EPICS environment. The device can be rotated by 90° to measure in both transverse directions.

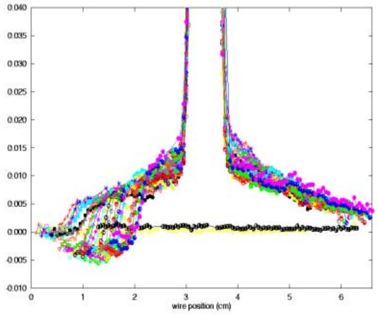

Figure 2. Slit scattering effects of about 1% of peak signal measured on the emittance device.

A beam stop capable of withstanding the full beam power at full pulse length was also developed using the same jaw design. In this case, the jaws are set at an opening angle of 3.3° and with zero gap width, and a back plate is used to catch any stray beam. The beam stop can be installed in the vacuum box in place of the slit.

4 BEAM COMMISSIONING RESULTS

4.1 Beam Transmission Measurements

As in the commissioning of the RFQ, MEBT beam transmission measurements were made as a function of the RF power in the RFQ. The results were in excellent agreement with TOUTATIS simulations. Beam loss in the MEBT itself was negligible as expected.

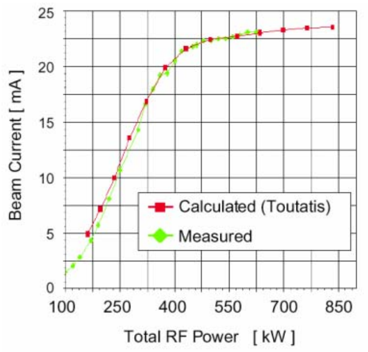

Figure 3. Calculated and measured beam transmission through the RFQ as a function of rf power.

4.2 Transverse Emittance Measurements

Fig. 4 shows an example of a measured MEBT emittance exhibiting a minute amount of halo. Normalized rms emittance sizes as a function of beam current are given in Table 1.

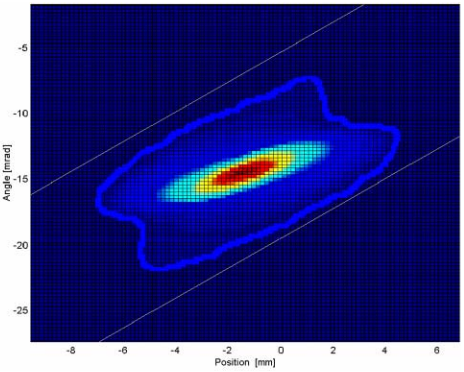

Figure 4. Measured horizontal MEBT emittance with hand-traced halo border at about 10^{-3} of peak value.

4.3 Beam Profile Measurements

Beam profiles were measured in five locations along the MEBT, and the results compare well with the beam dynamics calculations. The deviations from expected profile widths are within ±10%. Fig. 5 shows a typical wire profile measurement, where at first a horizontal wire crosses the beam, then a diagonal one, and finally a vertical wire.

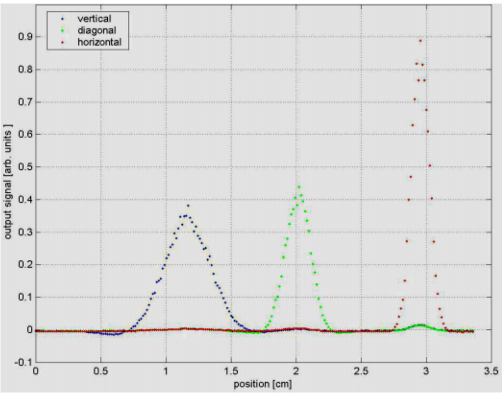

Figure 5. Example of a beam profile measurement.

Table 1. Measured MEBT emittances
No background subtraction except for slit scattering

Current mA	Rms Size π mm mrad	Condition
24	0.276	hor/unbunched
33.4	0.281	hor/unbunched
27	0.261	vert/unbunched
27	0.270	vert/bunched

5 ENDURANCE TEST

A round-the-clock endurance test was performed to verify the initial robustness of the system. The system was run at high duty factor, initially above 1%, and gradually increasing to about 3%. One week of testing resulted in no failures caused by beam operations.

6 PLANS FOR OPERATION AT SNS

The Front End was disassembled starting on June 3, and shipped to Oak Ridge during the following six weeks. It has already been reassembled at the SNS site, and a vacuum check has confirmed the integrity of all components, including windows. Low level RF measurements confirmed the proper positions of all RFQ drive loops that had remained installed on the cavity during shipment. The diagnostic beam-line will be used in Oak ridge to support the Front End commissioning activities later this fall. These activities include commissioning the final power rf systems and testing the MEBT choppers, both supplied by Los Alamos, as well as integrating all local infrastructure such as controls and timing. The re-commissioning of the Front End will be completed by the end of 2002.

7 CONCLUSIONS

The SNS Front End commissioning was highly successful and produced important results. All major parameters that were specified for the injector were individually demonstrated, including high-duty-factor operation and beam production, transverse emittances, and beam profiles. Issues that were not fully explored were the longitudinal emittance, due to the lack of an appropriate diagnostic device, and the ion-source antenna lifetime, which was tested to over 100 hours of operation only because time constraints did not allow a full test to the limit.

Among the concepts that were proven or further validated, probably the most visible ones are the effectiveness of the cesium-enhanced H^- production, electron removal at low energy, and beam transport in an electrostatic LEBT.

During commissioning, a proof-of-principle demonstration of the laser-based beam profile monitor was conducted by the ORNL and BNL collaborators [8].

8 ACKNOWLEDGEMENTS

The success with such a complex system would have never been possible without the effort and commitment by a large group of people. Among them are the SNS Controls group, in particular Dave Gurd, Ernie Williams and Erik Bjorkland; the SNS Beam Instrumentation group with Saeed Assadi, Wim Blockland and Dave Purcells, the LANL Beam Instrumentation group with Mike Plum, John Power, Matt Stettler, Chris Rose, Wym Christensen, Lisa Day; and staff from BNL, Peter Cameron and Craig Dawson; in addition, the SNS Accelerator Physics group with Marion White and John Galambos, as well as Paul Gibson, Rob Welton, and Martin Stockli gave valuable contributions.

Other essential contributions came from the EH&S group at LBNL, including Pat Thomas, Ken Barat, Tom Caronna and Ted DeCastro. The priceless help from the Front End Electronics and Mechanical Engineering groups is also acknowledged, mainly by Daryl Oshatz, Allan DeMello, Bill Abraham, Pete Cull, Tim Kuneli, Mark Regis, and Nathan Ybarrolaza.

9 REFERENCES

[1] M. White, “The Spallation Neutron Source,” these proceedings.

[2] R. Keller et al., “Progress with the SNS Front End Systems,” proceedings of the 2001 Particle Accelerator Conference, Chicago, IL, USA, June 2001, 70-72.

[3] A. Ratti et al., “The design of a high current, high duty factor RFQ for the SNS,” Proc. European Particle Accelerator Conference, Vienna, Austria, June 2000, 495-497.

[4] A. Ratti et al., “The SNS RFQ Commissioning,” these proceedings.

[5] A. Ratti et al. “Fabrication and Testing of the First Module of the SNS RFQ,” Proc. XXth International Linac Conference, Monterrey, CA, USA, August 2000, 911-913.

[6] L. Doolittle et al., “The SNS Front End LLRF System,” these proceedings.

[7] T.J. Shea et al, “SNS Accelerator Diagnostics: Progress and Challenges,” Proc. 2001 Particle Accelerator Conference, Chicago, IL, USA, June 2001, 512-516

[8] R. Connolly, “Laser Beam Profile Monitor Development at BNL for SNS,” these proceedings.