COMMISSIONING OF THE SNS FRONT-END SYSTEMS AT BERKELEY LAB*

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Abstract

Construction of a 2.5-MeV linac injector, the Front-End (FE) for the Spallation Neutron Source (SNS) project, was completed in the spring of 2002. Of the major FE subsystems, the rf-driven H^- ion source, the electrostatic LEBT, and the first of four RFQ modules had been commissioned by the spring of 2001, and commissioning of the remaining RFQ modules as well as the full system including the elaborate MEBT was carried out in Jan. through May, 2002. The Front End will be shipped to Oak Ridge, starting in June, 2002, and re-commissioned after installation at the SNS site. This paper gives an overview of FE major design features and experimental results obtained during the commissioning process at LBNL.

1 INTRODUCTION

The SNS accelerator systems are comprehensively discussed elsewhere [1]. They aim at delivering intense proton-beam pulses of less than 1-µs duration to the spallation target at 60-Hz repetition frequency and with an average beam power of 1.44 MW. The 1-ms long H^- macro pulses that are accelerated by the linac to 1-GeV energy have to be chopped at about 1 MHz frequency into 'mini pulses' of 645-ns duration, with 300-ns gaps.

LBNL has built the front end (linac injector) with its main beamline elements consisting of ion source, low-energy beam-transport section (LEBT), RFQ accelerator, and medium-energy beam-transport section (MEBT), as well as the ancillary systems needed to operate them. The beamline, without ancillary systems, is shown in Fig. 1. Some parts of the SNS front end, i.e. the rf power system for the RFQ and the MEBT chopper structures and their power supplies, were supplied by LANL; some diagnostic elements and associated electronics by LANL and BNL, and personnel from these laboratories as well as from SNS-ORNL participated in the commissioning. The SNS Front-End project has been described in detail elsewhere with an ample collection of references [2, 3] and the present paper emphasizes the latest design features and commissioning results.

Beam chopping is performed by two separate chopper systems located in LEBT and MEBT, respectively. The LEBT chopper removes most of the beam power during the mini-pulse gaps, and the MEBT chopper reduces the rise and fall time of the transported beam to 10 ns.

The main nominal parameters for the SNS Front End are listed in Table 1. The front end was assembled and commissioned at the Integrated Testing Facility at LBNL and will be shipped to ORNL in the summer of 2002.

2 ION SOURCE AND LEBT

Extensive details on ion source and LEBT design and further development efforts are given elsewhere [4]. The ion-source plasma is sustained by pulsed 2-MHz-rf power and confined by a multi-cusp magnet configuration. Pulse ignition is facilitated by maintaining a continuous, low-density plasma, driven by a separate 13.56-MHz generator. A magnetic dipole filter separates the main plasma from a smaller H^- production region where low-energy electrons help generating copious amounts of negative ions. A heated collar, equipped with eight cesium dispensers, surrounds this H^- production volume, and a very thin (about 1/2 mono layer) coating of cesium on the collar and outlet-electrode surfaces enhances the extracted beam current by a factor of three for a given rf power.

The outlet plate of the ion source contains a dipole-magnet configuration that creates a transverse deflecting field across the extraction gap, separates the extracted

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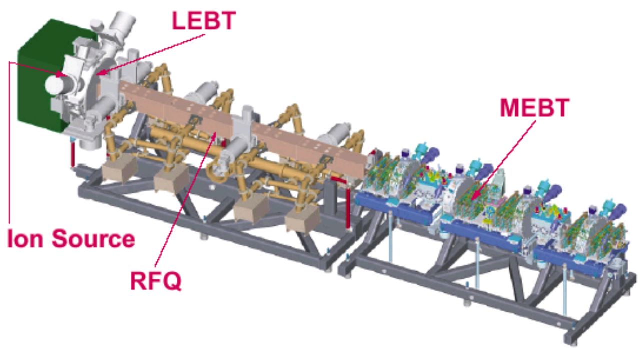

Figure 1: The 9-m long SNS front-end beamline.

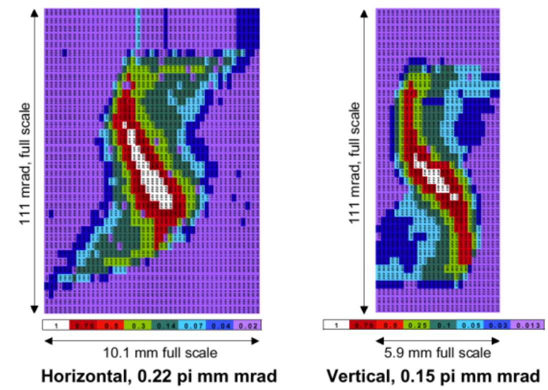

Figure 2: Transverse emittances of a 33-mA beam, taken at the LEBT exit. Background signals of 2.1% of peak intensity (horizontal) and 1.3% (vertical), respectively, were subtracted from the raw data.

electrons from the ion beam and steers them towards a 'dumping' electrode biased at 5 kV with respect to the outlet plate. Because this dumping field steers the ion beam as well, the entire plasma generator is tilted at an angle of about 3° against the LEBT axis to compensate for this effect. The angle can be adjusted as needed.

Table 1. FES Nominal Performance Parameters

Ion species	H^-
Output energy (MeV)	2.5
H^- peak current:	
MEBT output (mA)	38
Nominal ion-source output, assuming 80% RFQ transmission (mA)	50
Output normalized transverse rms emittance (π mm mrad)	0.27
Output normalized longitudinal rms emittance (π MeV deg)	0.126
Macro pulse length (ms)	1
Duty factor (%)	6
Repetition rate (Hertz)	60
Chopper system:	
Rise, fall time (ns)	10
Off/on beam-current ratio	10^{-4}

The LEBT serves five main purposes, i.e., beam formation, 2-parameter matching into the RFQ, steering in angle and transverse offset, pre-chopping, and gas pumping. A fully electrostatic system with two einzel lenses as focusing elements was chosen for the SNS LEBT. The second one of these lenses is split into four quadrants that can be biased with d.c. and pulsed voltages to provide angular steering as well as pre-chopping. The LEBT can also be mechanically offset against the RFQ axis.

Ion source and LEBT have been commissioned, and average beam pulse-currents up to 50 mA have been transported through the LEBT at 6% duty factor. Examples of emittances, measured using an Allison scanner, are shown in Figure 2. Peak beam-current values up to 68 mA have been measured at the beginning of the pulses.

3 RFQ

The 3.72-m long RFQ consists of four modules, built as composite structures with an outer GlidCop® shell enclosing four oxygen-free copper vanes. Peak surface fields reach 36 MV/m, and the total rf power is 640 kW during pulses. Water-cooled π-mode stabilizers [5] separate unwanted dipole modes from the main quadrupole mode. Static frequency tuning is achieved by 20 slug tuners per module, and dynamic tuning by adjusting the temperature difference between vane tips and the outer walls of the modules.

All modules have been conditioned together to full nominal rf gradient at 6% duty factor, and the field flatness is better than ±1% peak-to-peak.

The RFQ was commissioned with beam at duty factors around 0.1%. The main topics were transmission vs. rf power as shown in Fig. 3, transmission vs. injection energy, influence of LEBT steering and matching, and emittances vs. rf power and beam current.

Emittances were measured in one direction at a time, using a rotatable slit/wire-harp device. The measured effects of slit scattering have been subtracted from all RFQ (and later MEBT) emittance data, but no thresholding was applied on any of them. A measured vertical RFQ emittance is shown in Fig. 4.

A maximum beam current of 32 mA was recorded with the ion-source extraction gap increased by 4 mm to obtain better LEBT matching at moderate currents. This result indicates an actual transmission through the RFQ above 90% and reduces the beam-current goal for the ion source to about 43 mA.

The mini-pulse rise and fall times generated by the LEBT chopper were 25 ns, twice as fast as had been assumed for the design of the MEBT chopper target.

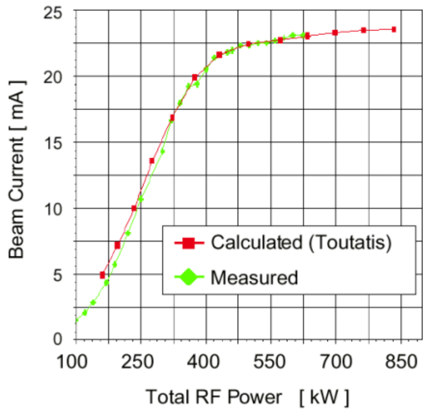

Figure 3: Simulated and measured transmission values for the RFQ, with an input beam of 35 mA, show excellent agreement.

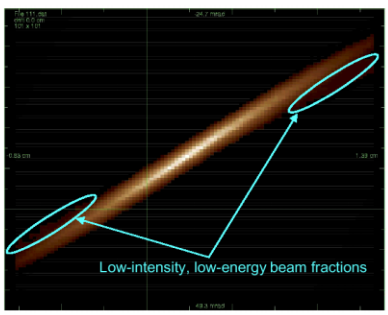

Figure 4: Vertical emittance of a 21.8-mA RFQ beam. The measured rms size of 0.325 π mm mrad includes a 65-keV beam fraction that carries very little current.

4 MEBT

The MEBT, shown in Figure 1, matches the beam from the RFQ through the MEBT chopper system and into the drift-tube linac currently being built by LANL. Fourteen quadrupole magnets and four rebuncher cavities provide transverse and longitudinal matching. An anti-chopper directs all particles back on axis that were deflected by the chopper during the rise and fall of the pulses and not fully intercepted by the target. Both chopper structures and their power supplies were provided by LANL.

Commissioning topics included beam transport without and with rebunchers; beam profiles; emittances; and the demonstration of 6% duty-factor operation. While the ion-source extraction gap was still 4 mm wider than nominal, 36 mA was initially transmitted. On the last day of testing, 50 mA was transported through the MEBT for several hours, exceeding the design goal of 38 mA by a comfortable margin. A round-the-clock beam test was performed over one week to ascertain the reliability of all front-end subsystems in integrated operation.

MEBT emittances such as the one seen in Fig. 5 show only slight signs of distortion, and the rms sizes are lower than those of corresponding RFQ emittances because the low-energy particles are lost along the beamline. Details of other MEBT commissioning efforts, especially pertaining to diagnostics, are given elsewhere [6].

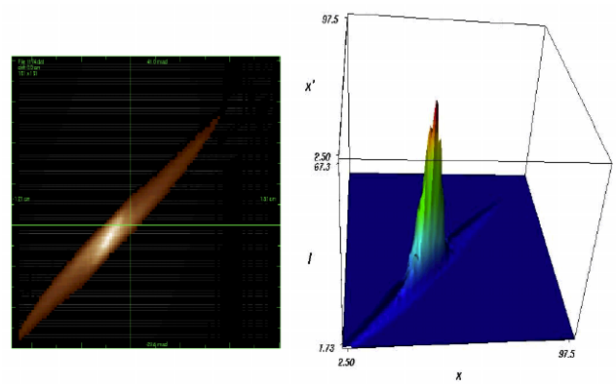

Figure 5: Vertical emittance of a 19.5-mA beam at the end of the MEBT. The rms size is 0.299 π mm mrad.

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