STATUS OF THE SNS FRONT-END SYSTEMS*

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Abstract

The Front-End Systems (FES) of the Spallation Neutron Source (SNS) project are to deliver a 52-mA H$^-$ ion beam at 2.5 MeV energy to the subsequent Drift-Tube Linac. The FES comprise an Ion Source, a Low-Energy Beam Transport (LEBT), an RFQ accelerator, and a Medium-Energy Beam Transport (MEBT). The macro-pulse duty factor is 6%, and the macro pulses have to be chopped into a mini-pulse structure with a time scale of hundreds of ns, to reduce beam losses and component activation during extraction from the SNS Accumulator Ring. This paper discusses the design features of the major FES subsystems and reports on their current status, aimed at a delivery to the main SNS facility in Oak Ridge in April 2002.

1 INTRODUCTION

The Spallation Neutron Source (SNS) project [1] is presently in the second year of its construction phase. The project is being carried out under a collaboration agreement among six U. S. National Laboratories, led by ORNL whose responsibilities include the project leadership. LBNL is building the front end with its main components consisting of ion source, low-energy beam-transport section (LEBT), RFQ accelerator, and medium-energy beam-transport section (MEBT). Some subsystems of the front end, i.e. the rf power system for the RFQ and the MEBT chopper structures with their power supplies, will be supplied by LANL.

The SNS accelerator systems 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 power of about 2 MW. The 1-ms long H$^-$ macro pulses that are accelerated in the linac to about 1-GeV energy have to be chopped into 'mini pulses' of 645-ns duration, with 300-ns pauses.

Chopping is performed in the front end 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.

The main requirements for the SNS Front-End Systems are listed in Table 1.The front end will be assembled and commissioned at the Integrated Testing Facility at Berkeley Lab before being shipped to ORNL in the spring of 2002.

Table 1. FES Key Performance Parameters

Ion species	H$^-$
Output energy (MeV)	2.5
H$^-$ peak current:	
MEBT output (mA)	52
Nominal ion-source output (mA)	65
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:	
Rise, fall time (ns)	10
Off/on beam-current ratio	10^{-4}

2 BEAM GENERATION

Earlier in its history, the SNS project had aimed at 1-MW average beam power on the spallation target, requiring only 35-mA of beam current to be injected into the RFQ. An 'R&D' ion source was built to demonstrate this current capability at 6% duty factor and to investigate the cesium enhancement and electron separation processes [2]. To provide a beam for injection into the first of four RFQ modules at 65 keV energy as early as possible, a 35-mA 'startup' ion-source/LEBT system was built even after the project goal changed to 2 MW, while design and construction of the final 65-mA 'production system' were undertaken in parallel. A schematic of the startup system is shown in Fig. 1.

The production ion-source/LEBT system has to generate 65 mA of beam current—not quite twice as much as the startup system because an increase in the circumference of the accumulator ring resulted in a slightly higher mini-pulse duty factor under the latest 2-MW scenario.

2.1 Ion Source

The H$^-$ ion source is derived from the SSC design [3] which had demonstrated beam currents in the 100-mA range at very short duty factor. The plasma generator utilizes a 2-MHz, rf-driven discharge, confined by a multicusp magnet configuration. A magnetic dipole filter separates the main plasma from a smaller H$^-$ production region where low-energy electrons generate copious amounts of negative ions. A heated collar, equipped with eight cesium dispensers, surrounds this H$^-$ production chamber.

The outlet plate of the plasma generator contains another dipole-magnet configuration that creates a deflecting field across the extraction gap in order to separate extracted electrons from the ion beam and steer them towards a 'dumping' electrode attached to the outlet plate. Because this dumping field steers the ion beam as well, the entire plasma generator is tilted at an adjustable angle

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with respect to the LEBT axis to compensate for the resulting kink.

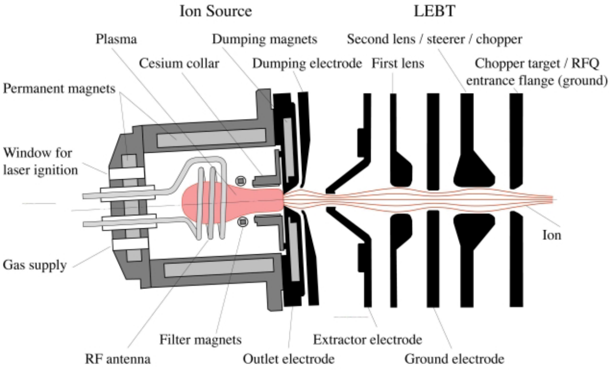

Figure 1: Schematic of the 35-mA startup ion-source and LEBT. Note that the actual filter and electron-dumping magnetic fields are oriented orthogonally to the illustration plane. The width of the ion beam is greatly exaggerated in this schematic to emphasize the focusing action of the double-lens system.

2.2 LEBT

The LEBT structure has to serve five main purposes, i.e., beam formation, 2-parameter matching into the RFQ, steering in angle and transverse offset, pre-chopping, and gas pumping. An earlier proton-LEBT design [4] had proven the viability of the purely electrostatic matching approach, and a similar configuration with two einzel lenses was chosen for the SNS startup LEBT, see Fig. 1 [5]. The second one of these lenses is split into four quadrants which can be biased with d.c. and pulsed voltages to provide angular steering as well as pre-chopping [6]. Transverse offset correction is achieved by moving the ion source and LEBT with respect to the RFQ.

The last LEBT electrode is part of the RFQ entrance wall, and on its upstream side it carries a diagnostic electrode made again from four insulated quadrants. During the pauses in between mini pulses, chopping voltages of ±2.5-kV amplitude and 300-ns duration are applied to opposing pairs of lens quadrants in a rotating pattern, directing the chopped beam alternatingly towards each of the four separation zones between the diagnostic-electrode quadrants. In this way, any parts of the beam that are not intercepted by the diagnostic electrode are prevented from hitting the RFQ vanes themselves whose accurate shapes could otherwise gradually be eroded by sputtering.

The LEBT-electrode shapes were optimized by simulating proton beams, using the 2-d code IGUN [7] in a novel way that allows introduction of finite ion temperatures into the calculation without experiencing unrealistic deformations of the plasma meniscus [8]. In essence, the plasma section of the problem is calculated with zero ion temperatures, and finite angles, corresponding to the assumed ion temperature, are added to all trajectories on the equipotential surface just 200 V below meniscus potential. This method was validated by comparing a few measured emittances with simulation results. The electrode shapes developed for the 65-mA production LEBT are shown in Fig. 2.

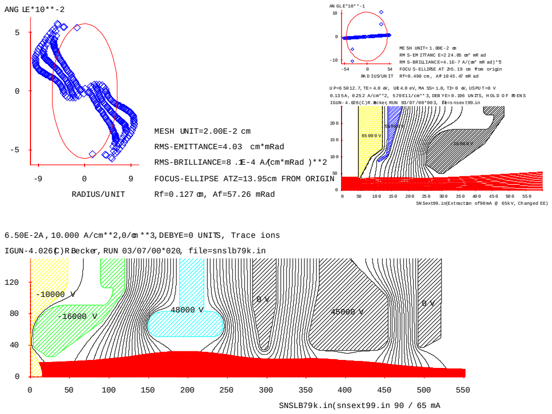

Figure 2: IGUN simulation of the 65-mA production LEBT, split into two major parts, i.e., extraction gap (top right) and main LEBT (bottom). The calculated transverse normalized rms emittance in the exit plane (see top left) amounts to 0.1 π mm mrad, leaving a considerable safety margin for the emittance of the actual beam.

2.3 Ion Source and LEBT Status

Startup ion source and LEBT are presently being commissioned at Berkeley Lab in the SNS-FES Integrated Testing Facility, and beam pulse-currents up to 42 mA have been obtained at 6% duty factor and transported through the LEBT [9]. 35 kW of peak rf power is needed to create the necessary plasma density for these results. The vertical normalized rms emittance of a 35-mA beam was measured by an Allison scanner as 0.17 π mm mrad. All electrons are removed from the ion beam at low energy and deposited on the outlet or dumping electrodes, as verified by operating the ion source with helium.

3 RFQ

The RFQ design [10] is derived from an earlier RFQ that has run for many years in the BNL AGS injector [11]. The SNS RFQ is 3.72-m long overall and consists of four modules built as composite structures with an outer GlidCop shell and four oxygen-free copper vanes [12]. The RFQ will accelerate the H^- beam from 0.065 to 2.5 MeV with an expected transmission far better than 80% [13]. Peak surface fields reach 1.85 Kilpatrick, and the total rf power consumption is 800 kW during pulses. Water-cooled π-mode stabilizers, following the JHC layout [14], separate unwanted dipole modes from the quadrupole frequency. Static frequency tuning is achieved by 20 stub tuners per module, and dynamic tuning by adjusting the temperature difference between vane tips and the outer walls of the modules.

Figure 3 shows the assembled first module before the final brazing operation. The main structure has now been completed and is being made ready for power rf tests, adding tuners, rf power couplers, rf pickup probes, vacuum manifolds, and cooling lines. The resonance frequency with tuners at nominal positions is very close to the design frequency of 402.5 MHz, and the field flatness is better than ±1% peak-to-peak.

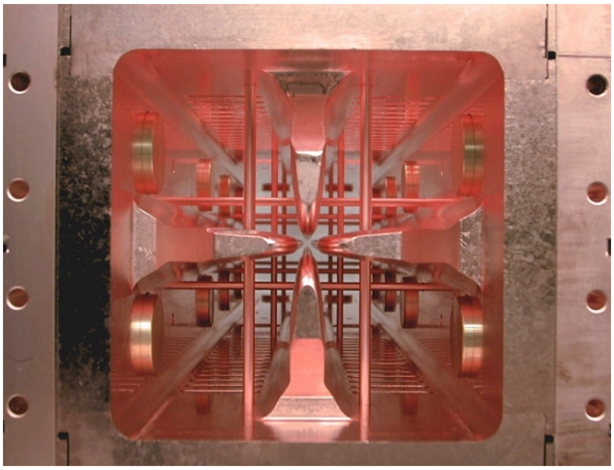

Figure 3: End-on view of the assembled RFQ Alpha Module prior to the final brazing operation. The upstream ends of the four vanes are seen at the center, with π-mode stabilizers penetrating the vanes horizontally and vertically.

4 MEBT

The MEBT [15], shown in Fig. 4, is 3.67-m long and has three main functions, i.e., matching the beam from the RFQ exit plane into the MEBT chopper plane, cleanup chopping, and matching the remaining particles into the drift-tube linac that is being built by LANL. Matching in both transverse and in the longitudinal direction is provided by 14 quadrupole magnets, arranged in three families, and four rebuncher cavities. The beam dynamics features of the SNS MEBT are discussed in detail elsewhere [12]; the hardest challenge for the lattice design is the limitation of the transverse emittance growth to 20%.

During the 10-ns rise and fall of the chopper pulses, the ion beam will be only partially chopped, and to get these parts of the beam back on axis an anti-chopper with the same functional characteristics as the chopper is inserted downstream of the chopper target.

The most critical component in the MEBT is the chopper target because of the extreme power density, reaching a peak level of 300 kW/cm^2 for a few ns duration. The engineering solution consists of a tilted, directly cooled TZM (molybdenum alloy) brazement with numerous cooling channels. The MEBT will also contain diagnostic elements [15] such as beam-position monitors, wire scanners to measure beam profiles, two fast current transformers, and an in-line emittance device.

All MEBT elements are grouped on three rafts that can be individually aligned. At present, all major components, including power supplies, are being fabricated or on order, and a chopper-target prototype is being built.

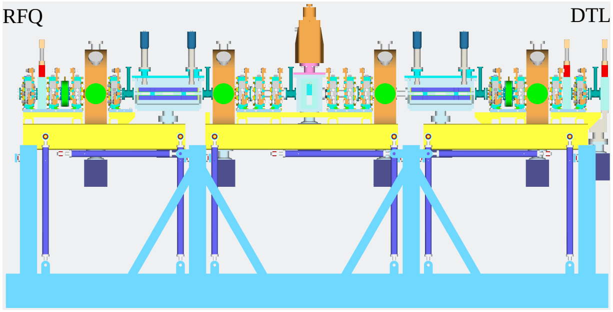

Figure 4: MEBT layout. The main elements are 14 quadrupoles, 4 rebuncher cavities, the chopper and antichopper structures, and the chopper target, at the center of the MEBT. Five ion pumps are connected to the beam line.

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