## Title

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# Status of the SNS H$^-$ Ion Source and Low-Energy Beam Transport System*

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**Abstract.** The ion source and Low-Energy Transport (LEBT) system that will provide H$^-$ ion beams to the Spallation Neutron Source (SNS)** Front End and the accelerator chain have been developed into a mature unit that will satisfy the operational needs through the commissioning and early operating phases of SNS. The ion source was derived from the SSC ion source, and many of its original features have been improved to achieve reliable operation at 6% duty factor, producing beam currents up to the 50-mA range. The LEBT utilizes purely electrostatic focusing and includes static beam-steering elements and a pre-chopper. This paper discusses the latest design features of the ion source and LEBT as well as some future improvements, gives performance data for the integrated system, and reports on commissioning results obtained with the SNS RFQ accelerator.

## INTRODUCTION

Berkeley Lab has just completed building the linac injector (Front End, FE) for the Spallation Neutron Source project (SNS) and is commissioning the entire system. The main subsystems are the H$^-$ ion-source, the low-energy beam-transport system (LEBT), the 2.5-MeV radio-frequency quadrupole (RFQ) accelerator, and the medium-energy beam-transport system (MEBT). Ion source and LEBT are the subject of this paper; their task is to create a 65-keV, 38-mA ion beam, to match and steer it into the RFQ, and to pre-chop it into mini-pulses of about 600 ns duration. The nominal duty factor is 6%, with 1-ms macro-pulse length and 60-Hz repetition rate.

Based upon the main design features of the SSC ion source [1], an R&D version of the SNS ion source was built first to demonstrate the viability of the chosen approach, utilizing an rf driven discharge inside a multicusp plasma generator with magnetic filter, cesium enhancement, and electron suppression at low energy [2].

For the LEBT, a purely electrostatic focusing system [3] was chosen, thereby avoiding time-dependent space charge compensation usually encountered with magnetic LEBTs. The production version of the ion source and LEBT [4] aims at generating and transporting a beam with 50-mA current, thought to be sufficient to satisfy the latest SNS design goal of 38 mA to be injected into the Linac while assuming a 20% beam loss in the RFQ. Actual RFQ transmission results [5], quoted below, indicate that a LEBT output current of about 44 mA should satisfy the SNS current goal.

A schematic view of ion source and LEBT is shown in Figure 1, below. By now, four plasma generators (including one "startup source") and one LEBT have been built and tested, and the specific design features and performance data of this production system are discussed in the following sections.

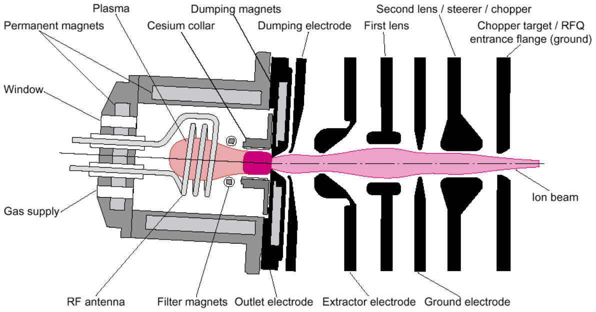

**FIGURE 1.** SNS Ion Source and LEBT schematic.

## ION SOURCE

The production-version ion sources aim at generating H$^-$ beams of up to 50-mA current. The goal for the normalized, transverse rms emittance is determined

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by the requirement of 0.2 π mm-mrad for the beam exiting the LEBT.

## Plasma Generation

The plasma is produced by a hydrogen discharge inside the multi-cusp vessel, sustained by tens of kW of 2-MHz rf power. The power is transmitted through an impedance-matching network to an antenna that consists of a 2-1/2 winding copper coil covered by a multi-layer porcelain coating. The efficiency of beam generation is about 1.0 mA per kW of rf power.

An antenna with 0.25-mm coating [6] underwent an endurance test at full duty factor, and the test was intentionally stopped after 107 hours while the ion source delivered 20 mA of beam current. An upgraded antenna with 0.8-mm thick 10-layer coating produces the same plasma density for a given rf power level as the thin version and should last significantly longer.

To reliably ignite the plasma at the beginning of every 1-ms pulse, a continuous, low-power discharge is sustained by an additional 13.56-MHz rf system. Not having to provide conditions suitable for ignition allows tuning the main discharge parameters towards optimum production of $H^-$ ions.

## $H^-$ Creation

Negative hydrogen ions are preferentially created in the space confined by the cesium collar, the magnetic filter field, and the outlet electrode, see Fig. 1. The filter field keeps energetic electrons that would destroy the $H^-$ ions away from the collar region. Volume production alone is sufficient only to generate about 15 mA of beam current; cesium enhancement is needed to reach the 50-mA level. For that purpose, the collar is fitted with eight cesium-chromate containers and is thermally isolated from the source body. The presence of a minute amount of cesium on the inner collar surface not only multiplies the abundance of negative ions in the discharge plasma by about a factor of three, but it also reduces the abundance of electrons in the extracted beam by one order of magnitude.

To best utilize the cesium, a freshly cleaned plasma generator is operated at full duty factor for about 15 min., heating the cesium collar to more than 500°C by forcing hot air through the collar wall and utilizing the rf power as a source of heat. After this initial conditioning, the collar is cooled down by room-temperature air and kept at about 280°C for optimal beam production. The cesium layer can then last for several days. Additional cesium reconditioning can be performed in-situ as needed.

Recently a new collar has been developed that seamlessly merges with the outlet aperture [7]. This design brings three major advantages: 1), it provides for keeping the surfaces around the outlet aperture at the same temperature as the collar; 2), with the help of an isolating centering ring, it allows precise aligning of the collar to the axis of the outlet aperture and at the same time biasing the entire unit to an optimal potential with respect to the source body [8]; and 3), it allows modifying the contour of the outlet aperture as discussed below, without having to build another main outlet flange. This integrated collar/outlet aperture has been fabricated but so far not yet been tested in the SNS ion source. Its design is shown in Figure 2.

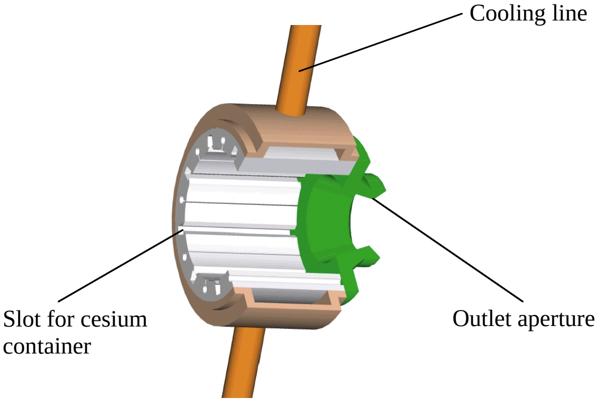

**FIGURE 2.** SNS Ion Source and LEBT schematic. Integrated cesium collar with slots for cesium containers (left) and outlet aperture (right). Heated or room-temperature air is conducted around the collar to stabilize the temperature.

# LOW-ENERGY BEAM TRANSPORT

## Electron Dumping

When a negative-ion beam is being extracted from a plasma, a substantial amount of electrons is extracted as well. This leads to the problems of increasing the space-charge density, especially near the outlet aperture, and of the power load to the structure where the electron beam is deposited. With the SNS ion source, the electrons are deposited on a dedicated ‘dumping electrode’ at moderate energies of about 5 keV, aided by a set of permanent magnets inside the outlet electrode. Usually some fraction of the electrons misses the dumping electrode entirely, and these electrons are accelerated to the full beam energy of 65 keV and hit either the extractor electrode or its support structure. A water-cooled shield has now been installed to absorb the associated heat load. It is expected that the new, integrated collar/outlet electrode described above will provide a more satisfactory solution to this problem.

Because of the steering action of the dumping magnetic field, not only on the electrons, but also on the ions, the entire ion source is tilted by an adjustable angle of ~3° with respect to the LEBT axis.

## Beam Simulations

For the earlier design work, the positive-ion code IGUN [9] had been used, approximating the electron space charge by increasing the assumed ion current in the volume near the meniscus. The negative-ion version of the code PBGUNS [10] appears to better simulate the beam formation process [11] and was used to design the new outlet aperture contour.

## Principal LEBT Functions

Apart from forming the beam, the main purpose of the LEBT is to transport it to the RFQ and match the injection requirements. To efficiently pump the gas load produced by the plasma generator the electrode support structures were given highly transparent shapes.

The focusing action of the two-lens electrostatic system, captured in a tuning matrix, works as predicted by simulations, but generation of less than nominal beam current results in a narrower beam size inside the first lens and effectively reduces its focusing power. To widen beams of less than 35 mA during RFQ commissioning, the extraction gap was increased by 4 mm as compared to the nominal size of 20 mm.

For pre-chopping and static steering, pulsed voltage signals of ±2.5 kV and, independently, dc potentials are applied to the four quadrants of the center electrode of the second lens. Not all of the chopped beam is intercepted by the ring target on the LEBT-exit/ RFQ-entrance electrode; the remaining particles are deposited inside the RFQ cavities

## BEAM RESULTS

The nominal beam-current goal of 50 mA pulse average measured at full 6% duty factor downstream of the LEBT was reached about a year ago, still with the nominal gap width installed. The peak current at the beginning of every pulse even reached 68 mA. With the extraction gap increased by 4 mm for RFQ commissioning, up to 36 mA were measured, and the pulse shape was much more uniform.

The emittances show pronounced distortions at the 10% intensity level, but after subtracting back-ground signals from the raw data, the normalized rms sizes are very close to or even better than the nominal values of 0.2 $\pi$ mm mrad.

A round-the-clock endurance test of the ion source and LEBT was conducted over more than a week, continuously producing beam of about 25 mA current at 3% duty factor, with few interruptions. It proved that the beam-generating system is ready to support commissioning of the SNS accelerators and even SNS operations for the first few years.

In fact, the commissioning of the SNS RFQ at low duty factor [5] was aided by very stable performance of Ion Source and LEBT, and up to 33 mA were transmitted, out of about 36 mA that had been injected.

The functionality of the LEBT pre-chopper system has been tested as well, and rise and fall times of 25 ns were measured, better than the nominal requirement by a factor of 2. The beam signals were not clear enough to allow a precise determination of the pre-chopper attenuation factor, but a value around $1x10^{-3}$ appears quite plausible from extrapolations of results obtained at less than nominal chopping voltages.

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