BREAKING THROUGH 100 mA H^- ION SOURCE OUTPUT CURRENT AT SNS*

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Abstract

The performance of the SNS H^- ion source was significantly improved over the years with a primary emphasis on operational lifetime and reliability. The recent developments in support of the SNS Proton Power Upgrade (PPU) have resulted in a remarkable boost in the ion source output current, increasing from the existing capability of ~60 mA to more than 100 mA. This paper briefly reviews the ion source reliability improvements and discusses the design and diagnostics of recent beam current enhancement.

INTRODUCTION

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is a large-scale accelerator-based pulsed neutron facility. The accelerator system of the SNS includes a 65 keV injector, a 2.5 MeV RFQ, a high energy Linac chain (warm Linac + superconducting Linac), and a proton accumulator ring. The injector consisting of a H^- ion source and an electrostatic LEBT provides H^- beams with the required current intensity and time structure for the SNS operation. SNS has recently undertaken a major upgrade to double the proton beam power from 1.4 MW to 2.8 MW, which involves Linac beam energy upgrade from 1.0 GeV to 1.3 GeV, Linac beam current increase from ~35 mA to ~50 mA, and a reduction of chopped beam fraction. The SNS H^- ion source reliably supported the SNS 1.4 MW operation in the past couple of years with ~55 mA beam current operating at 6% duty-factor (1.0 ms, 60 Hz) covering 3-4 months long SNS run cycles. This established performance of the ion source could reach the requirements set forth by the new beam power goal. However, it is essential to have a sufficient beam current margin to allow operational flexibility and reliability.

THE SNS H^- ION SOURCE

The SNS ion source is a multicusp-confined, RF-driven, Cs-enhanced H^- ion source. This type of ion source was developed at Lawrence Berkeley National Laboratory (LBNL) initially for the Super-conducting Super Collider project and then for the Spallation Neutron Source project in 1990s and early 2000s. Since the ion source was operated at SNS starting in 2002, it has been further developed for long lifetime (several months), highly reliable, persistent high current (up to 60 mA) H^- beams for 1.0 ms pulses repeating at 60 Hz [1-9]. Figure 1 shows a cutaway view of the SNS H^- ion source with its key components denoted. The ion source plasma is driven by a 2 MHz RF through a porcelain-coated, water-cooled copper-tube RF antenna. The 2 MHz RF is capable of operating at 60 Hz with 1 ms pulse length and a power level up to 80 kW for high-density plasma generation. To facilitate fast and reliable ignition and buildup of the 2 MHz high-density plasma pulses, a low-density background plasma is generated and maintained in the same chamber with a continuous, low power (~300 W) 13.56 MHz RF applied on the same antenna. A pair of rod magnets provide plasma filtering for creating a low electron temperature plasma region favorable for H^- formation. A solid reaction Cs dispenser system (Cs_2CrO_4 + Zr, Al) is used for ion source cesiation. A Mo cone located near the ion source outlet aperture enhances H^- yield through negative ion conversion on its properly cesiated surface area. The co-extracted electrons are separated from the H^- beam and dumped on the e-dump electrode by a transverse magnetic field generated in the ion source extraction region by an array of magnets that are embedded in the outlet electrode. The extracted H^- beam is coupled into an electrostatic LEBT which transports and injects the beam to the RFQ.

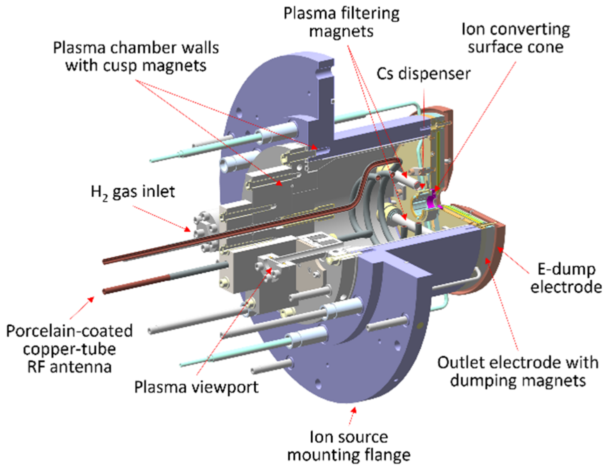

Figure 1: A cutaway view of the SNS H^- ion source.

The significant improvements which have contributed to the high-performance ion source operation include:

- Quality improvements of antenna coating (material composition, layer thickness, and rigorous inspection) allowing the ion source lifetime extension from the original 2-3 weeks to >4 months.
- RF systems improvements (relocation of RF amplifiers from ion source high voltage deck to ground potential, frequency shift and amplitude modulation at the start and end of the 2 MHz RF pulses, optimization of 13.56 MHz RF matching) enhancing the ion source plasma ignition and operational reliability.

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* Work supported by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the US Department of Energy (DOE)

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- Optimizations of ion converter material choice and surface geometry, improvement of Cs system thermal control, refinement of cesiation process, and standardization of the workflow of ion source rebuilding, installation and operation enabling persistent high current (~ 60 mA) with reduced performance variations.
- Electrical and mechanical improvements for the LEBT system mitigating severe arcing and facilitating beam-based ion source alignment.
- Upgrades of support systems (increased pumping, dual-bottle H_2 gas delivery, improved cooling arrangement) making the ion source operation more resilient.

NEW BOOST OF ION SOURCE OUTPUT

Experimental Setup and Results

To gain an adequate operational margin of beam current for the PPU requirement, the ion source extraction system was reexamined for optimization. A schematic of the SNS ion source extraction system is shown in Fig. 2. On the ground of the established operational reliability and performance consistency, the first and simpler step taken was increasing the ion source outlet aperture (extraction aperture) [9, 10]. The existing extraction aperture has a diameter of ϕ = 7 mm. An ion source was built with increased extraction aperture sizes, ϕ = 8 mm and ϕ = 9 mm, and the beam current outputs, transverse emittances, and operational compatibility with the existing infrastructure were tested on the SNS ion source test stand (ISTS) which is essentially identical to the SNS front end injector. The ISTS is equipped with a diagnostics chamber housing a faraday cup for beam current measurement and a set of emittance scanners for emittance measurements in both horizontal and vertical planes (see Fig. 3).

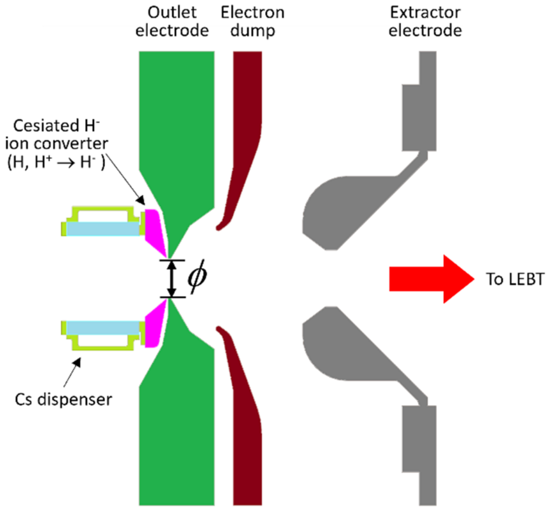

Figure 2: Extraction system of the SNS H$^-$ ion source.

As shown on Fig. 4, the output beam current of the ion source is significantly increased with the larger extraction apertures. Especially, with ϕ = 9 mm, the beam current broke through 100 mA for the ion source typical operational RF power of ~55 kW. At a further elevated RF power level of ~70 kW, the beam current reached 125 mA.

For larger extraction apertures, the beam output enhancement effect from the extraction field strength (potential difference between the ion source outlet and the extractor electrode) is also stronger.

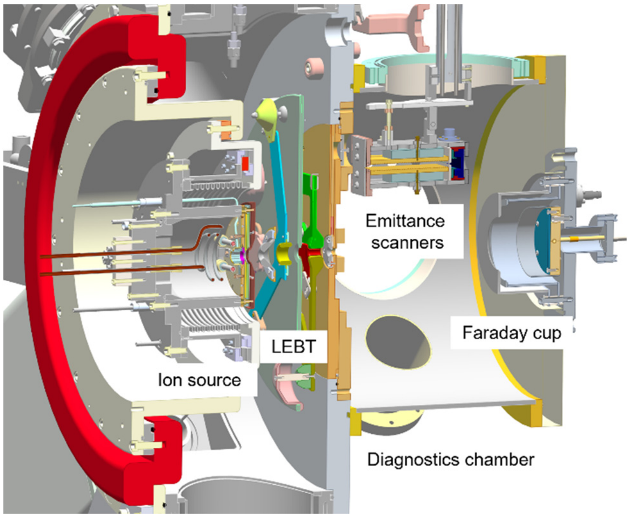

Figure 3: SNS ion source test stand.

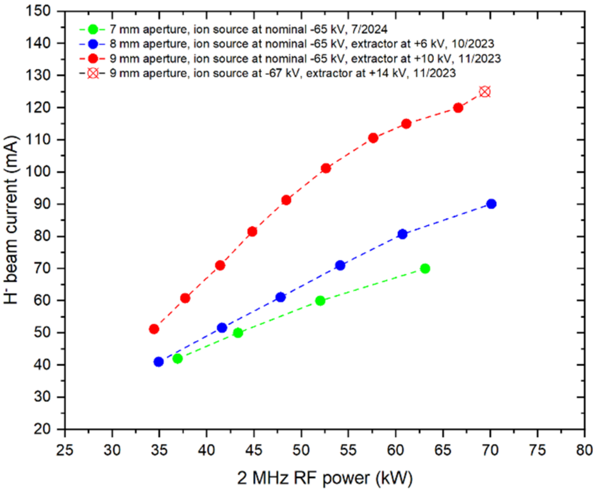

Figure 4: Beam current vs. RF power curves for 3 different sizes of extraction aperture.

Figure 5 shows the measured beam emittance vs. current intensity curves for the 3 different extraction aperture sizes. For same beam currents, the emittances are smaller for beams extracted from larger apertures. For up to ~100 mA extracted beams from a ϕ = 9 mm aperture, the emittances both in horizontal and vertical planes are within the SNS RFQ transverse emittance acceptance.

To validate the beam current extracted from the enlarged extraction apertures are compatible with the downstream acceleration component, an ion source with a ϕ = 9 mm extraction aperture was tested on the SNS front end accelerating beam through the RFQ. Beam currents up to 75 mA (an administrative upper limit) were delivered to the RFQ entrance. As shown in Fig. 6, ~90% beam transmission through the RFQ was achieved for input beam currents up to ~60 mA, and ~80% for a 75 mA input beam yielding 60 mA output from the RFQ as expected based on the SNS RFQ design. These results indicate the newly boosted beam output capability of the SNS ion source could provide a sufficient beam current margin for the SNS PPU 2.8 MW operation requirement. Ongoing test operation of an ϕ = 9 mm ion source on a 2.5 MeV RFQ Beam Test Facility also confirms operational compatibility with an RFQ. It is also worth noting that similar outlet aperture modifications have been undertaken at other laboratories which have also met with success [11]

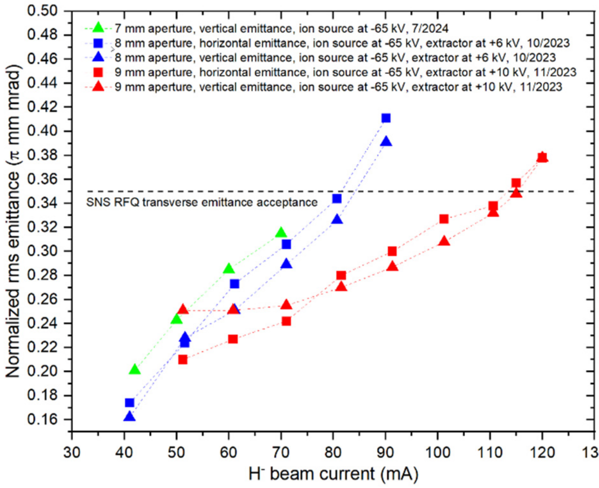

Figure 5: Beam emittance vs. current intensity for 3 different sizes of extraction aperture.

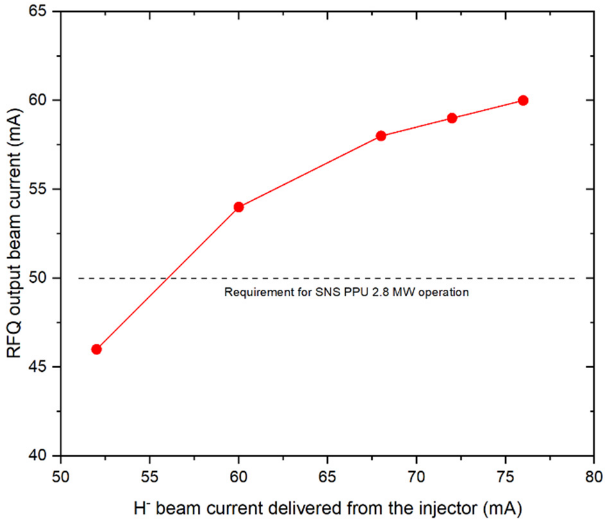

Figure 6: Test of an ϕ = 9 mm ion source for the RFQ.

Issues, Mitigations, and Outlook

As compared to the existing production ion sources with ϕ = 7 mm extraction aperture, the larger aperture ion source, e.g. ϕ =9 mm, requires higher (~30%) hydrogen gas flow rate for plasma ignition stability and optimal beam current. Vacuum upgrade for increased pumping is planned and testing of a 27.12 MHz RF system is underway to upgrade the existing 13.56 MHz RF as a more efficient driver for the background plasma [12].

The larger aperture ion source also causes heavier loads (both ions and electrons) on the electron dumping electrode and the extractor electrode. An optimized version of e-dump circuit, Fig. 7, is installed to stabilize the voltage supply output during the ion source pulses. The e-target (for a small fraction of co-extracted electrons that escaped the e-dump electrode) attachment on the extractor electrode has been modified to provide active cooling for the extractor electrode, Fig. 8.

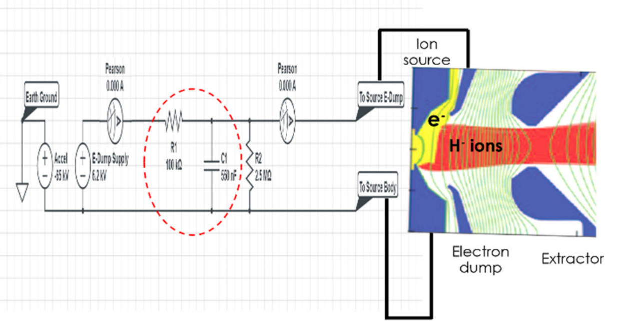

Figure 7: RC circuit optimized for ϕ = 9 mm ion source.

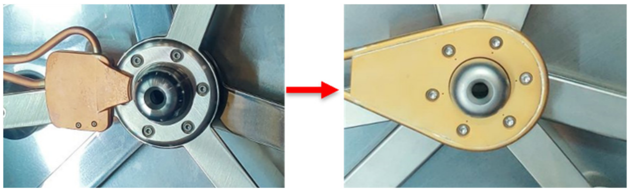

Figure 8: Modified cooling attachment for the extractor.

Measured beam waveforms seem to suffer severe distortion during transit through the LEBT at very high current (>100 mA) as seen in Fig. 9. We are looking into design improvement options for the existing electrostatic LEBT and also revisiting the 2-solenoid magnetic LEBT concept that was considered in the earlier years of SNS [13].

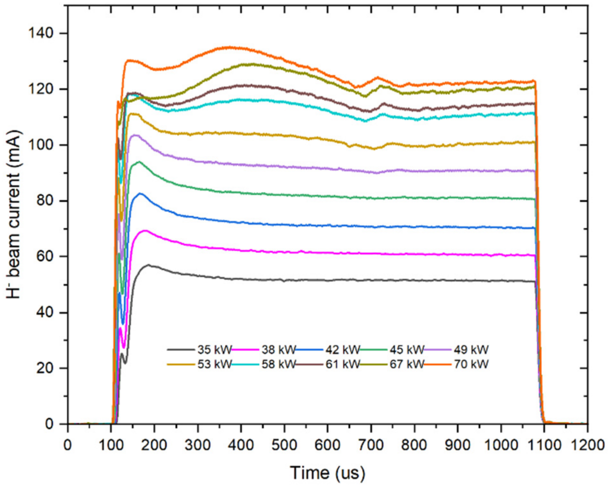

Figure 9: Beam pulse distortion at very high current.

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