OPERATION OF THE SNS ION SOURCE AT HIGH DUTY-FACTOR

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Abstract

The ion source for the Spallation Neutron Source* (SNS) is a radio frequency, multi-cusp source designed to produce ~ 40 mA of H^- with a normalized rms emittance of less than 0.2 pi mm mrad. Once the SNS is fully operational a beam current duty-factor of 6% (1 ms pulse length, repetition rate of 60 Hz) will be required to inject the accelerator. To date, the source has been utilized in the commissioning of the SNS accelerator and has already demonstrated stable, satisfactory operation at beam currents of ~30 mA with duty-factors of ~0.1% for operational periods of many weeks. Very little data exists describing source performance at higher duty-factors over sustained run-periods. This report presents the results of four tests, each ~1 week in length, in which the ion source was tuned for maximum beam current and operated at elevated duty-factors in the range of 2-7%.

INTRODUCTION

The Spallation Neutron Source (SNS) is a second-generation pulsed neutron source dedicated to the study of the dynamics and structure of materials by neutron scattering. It is currently under construction at Oak Ridge National Laboratory (ORNL) [1]. In order to meet the baseline requirement of 1.44 MW of beam power, the ion source must produce ~40 mA of H^- within a 1-ms pulse at a repetition rate of 60 Hz (6% duty-factor).

To date, the ion source has been utilized in commissioning the SNS Front-End (FE) both at LBNL [2] and ORNL [3] as well as the first three modules of the Drift Tube Linac (DTL) [4]. Although commissioning exercises at LBNL and ORNL have briefly demonstrated operation at the design goal of 38 mA at large beam duty-factors, the vast majority of these commissioning periods were spent with the ion source operating at very low beam duty-factors: ~0.1%.

*SNS is a collaboration of six US National Laboratories: Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Thomas Jefferson National Accelerator Facility (TJNAF), Los Alamos National Laboratory (LANL), 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. Department of Energy.

LBNL did, however, perform an endurance test in which the ion source was operated for ~5 days with a duty-factor of 2-3% delivering ~25 mA of beam current.

It is interesting to note that during the DTL commissioning period, the availability of the ion source and Low Energy Beam Transport (LEBT) was 98%, a marked increase from the 86% experienced during ORNL FE commissioning. This improvement can be attributed to several factors: i) improved design of the LEBT lens insulators, ii) improved supporting infrastructure including the hot spare stand and the availability of spare parts, and iii) increased operational experience of the ion source staff.

Given the lack of experience [5] operating the source over multi-day periods near the required duty-factor of 6%, we are currently performing ion source tests in the beam duty-factor range of 2-7% on a test stand capable of unattended, continuous operation. Two identical ion sources have been tested several times over the course of ~1 week run periods while having their performance and operational parameters electronically logged [6].

THE H^- MULTICUSP ION SOURCE

A schematic diagram of the H^- ion source is shown in Fig. 1. The source plasma is confined by a multicusp magnet field created by a total of 20 samarium-cobalt magnets lining the cylindrical chamber wall and 4 magnets lining the back plate. Pulsed RF power (2 MHz, 20-60 kW) is applied to the antenna shown in the figure through a transformer-based impedance-matching network. The plasma is sustained between pulses of the high-power RF by continuous application of ~200 W of 13.56 MHz power to the same antenna. A magnetic dipole (150-300 Gauss) filter separates the main plasma from a smaller H^- production region where low-energy electrons facilitate the production of large amounts of negative ions. An air heated/cooled collar, equipped with eight cesium dispensers, each containing ~5 mg of Cs_2CrO_4, surrounds this H^- production volume. The RF antenna is made from copper tubing that is water cooled and coiled to 2 1/2 turns. A porcelain enamel layer insulates the plasma from the oscillating antenna potentials [7]. More details of this source design can be found in reference 8.

ION SOURCE TEST STAND

The ion source test stand is located in the FE building, several meters away from the SNS FE, where it serves as a platform for performing continuous 24/7 ion source tests, an immediate source of spare parts for the FE and a vessel to test and check FE design improvements prior to their implementation. It consists of an ion source, LEBT, diagnostics chamber and enclosed high voltage platform containing the source electronics and gas-feed system [6].

The diagnostics chamber consists of horizontal and vertical Allison-type emittance scanners [9], a toroidal Beam Current Transformer (BCM), a cooled retractable and a fixed-position Faraday cup. Currently about 80% of the ion source services are computer controlled, monitored and logged using EPICS software [10]. These systems include: 2 and 13.56 MHz RF generators, source and LEBT high-voltage supplies, the electron dumping electrode supply, a directional coupler monitoring RF power, a current transformer monitoring RF antenna current and the beam diagnostic equipment described above.

Considerable effort is being directed at improving system electromagnetic compatibility, allowing stable operation in the elevated noise environment of high duty-factor operation. Both RF and arc-down noise sources have been reduced through better shielding, grounding and cable routing. Sensitive equipment is also being made more robust in the increased noise environment by filtering and improving shielding [11].

SOURCE PERFORMANCE AT HIGH DUTY-FACTOR

Three nearly identical ion sources were shipped from LBNL to ORNL along with the entire front end system [2,3]. Source # 1 has been in nearly continuous service on the SNS accelerator serving to commission the machine. Sources # 2 and 3 have been employed in this study, each being run twice on the ion source test stand for a period of ~1 week. The beam was measured using the BCM located at the entrance to the diagnostic chamber (described above) and delivered to a Faraday cup located at the exit of the diagnostic chamber. Fig. 2 shows the H^- beam pulse trace produced from the droop-corrected BCM as well as the Faraday cup signal. Note some of the beam is lost due to vignetting caused by the Faraday cup entrance aperture.

Prior to each run, the ion source was thoroughly cleaned using 15 µm diamond-grit sandpaper, fresh Cs-dispensers were installed and a new antenna was added. After the source was mounted, the system was thoroughly leak-checked with a He leak detector. The source was then started with a Low-Duty-Factor (LDF) plasma, created by delivering RF pulses to the antenna (2MHz, 20-30 kW, pulse width~100 µs, repetition rate~10 Hz).

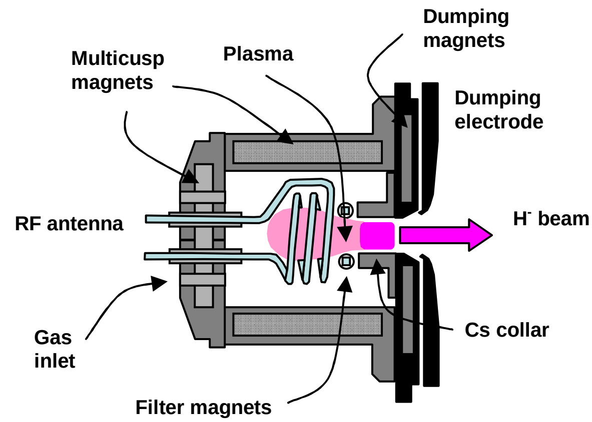


Figure 1: Schematic diagram of the SNS ion source.

The source was typically allowed to condition in this fashion for a few days to insure sufficient out-gassing and cleaning of the ionization surfaces of the source. Next, while delivering beam, the source was cesiated by raising the collar temperature to 550C from its nominal operating range of 200-300C for ½ hour by restricting cooling air flow. Finally, after 1 cesiation, the source was ramped to higher duty-factor by increasing the RF pulse length (typically to 1-1.2 ms) and repetition rate (30-60 Hz); the highest duty-factor reached was ~7 %. It was necessary to exceed the beam duty-factor requirement of 6% since the SNS will be unable to accelerate the initial peak seen in Fig. 2 due to excessive emittance in this region of the pulse.

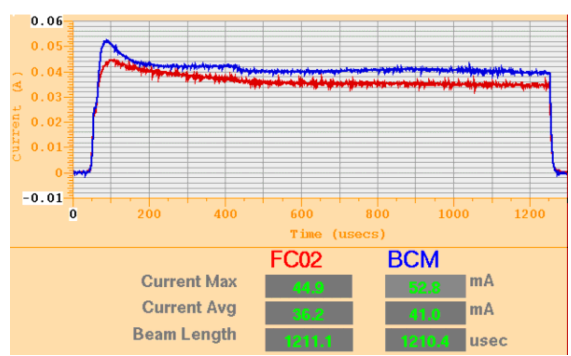
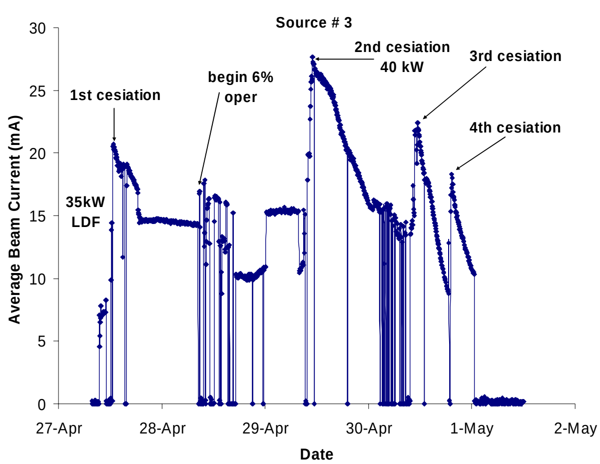


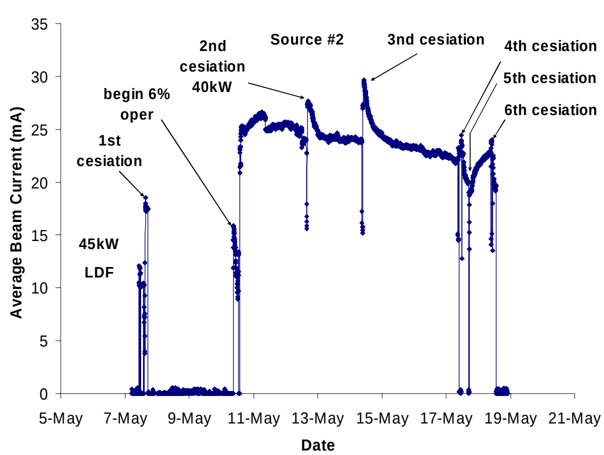
Figure 2: Typical H^- beam pulses delivered through the BCM (Blue-upper) and into the Faraday cup (Red-lower).

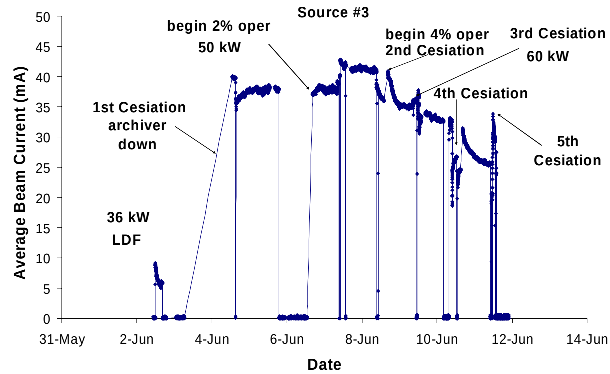
Once high-duty factor operation was established, the RF power was adjusted to give maximum beam current, typically 35-60 kW. The Cesiation process described above was repeated as needed to keep the beam intensity high. Fig. 3 shows the average beam current record of each run measured with the BCM corrected for droop and averaged over the entire pulse. Changes in RF power and duty-factor as well as cesiations are noted in each figure. The vast majority of the source downtime resulted from system trips or source instabilities which occurred during unattended periods. Had an operator been present the beam could have been continuously available. The beam current was then sustained for ~1 week, long enough to resolve the beam current trend (unless the beam could not be increased above 20 mA, in which case the run was terminated). Note that a 6% duty-factor was not reached in the early June run due to insufficient cooling of the electron dump on the extractor electrode of the LEBT, a condition which has since been corrected.

After the source was run it was inspected and, in each case, the Cs collar was found discolored and the antenna conditions were as follows: April run: small puncture through coating near the leg outside of the plasma region; May run: several punctures in coating in plasma region; early June run: no damage; late June run: antenna coated with conductive material but no punctures. These sources were operated with duty-factors of 6% or greater for a total of 14 days producing an average beam current of 23.4 mA.

It is clear that in order to meet the design goal of 40 mA much ion source development work still lies ahead both in terms of improving operational techniques as well as in design innovation. Several projects are currently ongoing which hold the promise of boosting source output and lifetime: external antenna [12] and improved Cs collar [13].







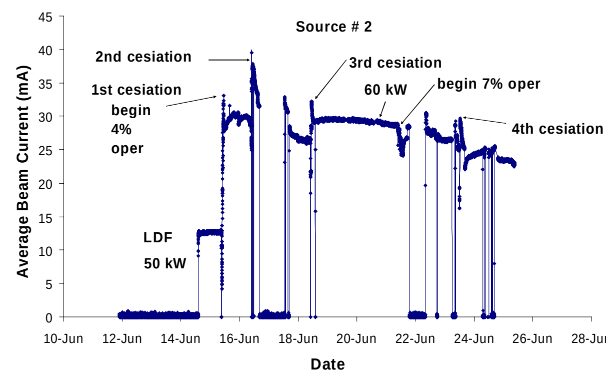


Figure 3: Average beam current measured by the BCM. Changes in RF power and duty-factor are noted.

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