ADVANCES IN THE PERFORMANCE OF THE SNS ION SOURCE

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Abstract

The ion source developed 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 π·mm·mrad. To date the source has been utilized in commissioning the SNS accelerator, delivering beams of 10-50 mA with duty-factors of typically ~0.1% for operational periods of several weeks, achieving an availability of ~99%. Ultimately the SNS facility will require beam duty-factors of 6% (1 ms pulse length, 60 Hz repetition rate, 21 day run-period). Over the last year, several experiments were performed in which the ion source was continuously operated at full duty-factor and maximum beam current on a test stand. Average beam attenuation rates of ~5 mA/day were observed and beams in excess of 30 mA could only be sustained for periods of several hours. Recently, a breakthrough in our understanding of the Cs release process has led to the development of a new source conditioning technique which resulted in a dramatic increase in beam persistence with time. H^- beam attenuation rates have been improved to ~0.4 mA/day, allowing beams in excess of 30 mA to be delivered continuously at full duty factor for periods of ~16 days.

INTRODUCTION

The Spallation Neutron Source (SNS) is a large multinational user facility dedicated to the study of the dynamics and structure of materials by neutron scattering and is currently under construction at Oak Ridge National Laboratory (ORNL) [1,2]. In order to meet the baseline requirement of 1.4 MW of beam power on target, the ion source must produce ~40 mA of H^- within a ~1.2 ms pulse at a repetition rate of 60 Hz (7% duty-factor). An ion source pulse of ~1.2 ms is required to make a flat beam pulse of 1 ms due to the characteristic overshoot of beam current from the source during the first 100-200 μs.

To date, the ion source has been utilized in commissioning the SNS Front-End (FE) both at LBNL [3] and ORNL [4], the Drift Tube Linac (DTL) [5] and the Coupled-Cavity Linac (CCL) [6]. During these campaigns the ion source availability increased from 86% during FE re-commissioning to 95% during DTL commissioning and most recently to 99% during CCL commissioning. Much of this early improvement resulted from an increase in reliability of the Low Energy Beam Transport (LEBT) which matches the beam extracted from the source into the RFQ. This was accomplished by improving the design of the insulators holding the LEBT electrodes [7]. Although commissioning at LBNL and ORNL have briefly demonstrated operation at the design goal of 38 mA at the exit of the RFQ 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 of much less than 1%.

Given the lack of performance data for the source operating at full duty-cycle over longer periods, we have performed 9 ion source and LEBT test runs at a duty-factor of 7.4% on our test stand with interlocks allowing unattended operation [7,8]. During the course of these tests a novel source conditioning technique was developed which has led to a dramatic improvement in the persistence of the ion beam with time.

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 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 negative ions. An air heated/cooled collar, equipped with eight cesium dispensers, each containing ~5 mg of Cs in the form of Cs_2CrO_4 mixed with elemental Al and Zr, 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 [9]. More details of this source design can be found in reference 10.

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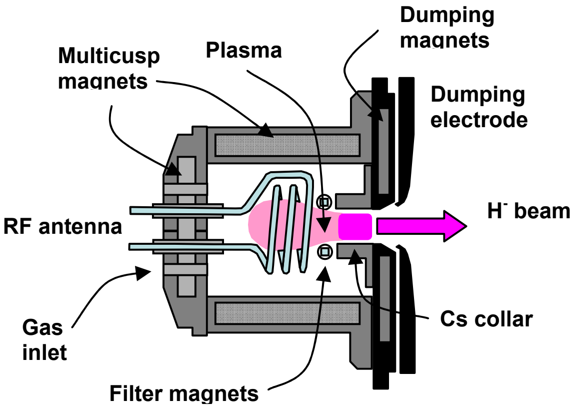

Figure 1: Schematic diagram of the SNS ion source.

ION SOURCE TEST STAND

Located near the FE is the ion source test stand where new ion source modifications are tested and continuous 24/7 tests are performed unless parts are needed for the repair of the FE. It consists of an ion source, a LEBT and diagnostics chamber, with an enclosed high voltage platform containing the source electronics and gas-feed system [6]. The diagnostics chamber consists of a horizontal and a vertical Allison emittance scanner [11], a toroidal Beam Current Monitor (BCM) and a water-cooled, high-power Faraday cup. Other diagnostics include a fiber-coupled optical spectrometer (300-1400 nm) viewing the plasma from a fixed position and a residual gas analyzer sampling the vacuum. Most of the system is now computer controlled and monitored.

EARLY ION SOURCE RUNS

A series of 7 experimental runs were performed in which a thoroughly cleaned ion source was mounted on the test stand, conditioned, brought to full duty-factor and optimized for maximum beam current. The source was then run continuously for ~1 week while recording the beam current exiting the electrostatic LEBT. If the beam current exceeded 30 mA the run period was extended.

The following conditioning / operating procedure was employed as recommended by LBNL: the source was started with a low-duty-factor plasma (~0.1%) and the Cs collar was heated to ~300C. After several hours of conditioning in this state, the duty-factor of the source was increased to ~3% and air flow to the Cs collar was terminated allowing the collar temperature to reach ~550C injecting Cs into the source. This condition was held for ~30 min. and then heated air flow was restored returning the collar temperature to its nominal operating range of ~300C. The source was then ramped to full duty-factor by increasing the RF pulse length and repetition rate. Once high-duty factor operation was established, the RF power was adjusted to give maximum beam current, typically 40-60 kW. The Cesiation process described above was repeated as needed to keep the beam intensity high.

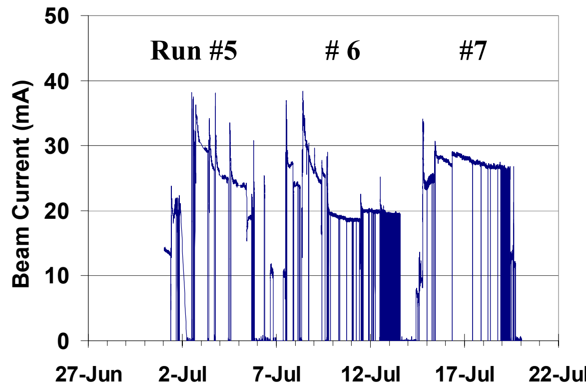

Figure 2: Average pulse current records for three experimental runs showing the best performance achieved using the original conditioning procedure.

Fig. 2 shows the beam currents for the three best performing experimental runs out of the seven which employed the original conditioning technique. The average beam current across the droop-corrected pulse as measured by the BCM is plotted. Notice the beam current only exceeds 30 mA for periods of several hours. The spikes extending upward from the baseline show the effects of cesiations which were performed 3-4 times during each run. The spikes extending downward to zero are system trips which could not be reset during periods of unattended operation. A detailed account of experimental runs 1-4 can be found in reference 7.

DATA ANALYSIS

It is well known that Cs-enhanced, multicusp ion sources produce H^- in both in the plasma volume and on Cs-coated surfaces which are subjected to plasma bombardment [12]. During each run we observe relatively constant light emission from the plasma using the spectrometer, suggesting plasma conditions, and therefore volume ionization, remain essentially constant over time. We, therefore suspect the decreased beam intensity is related to a decrease in surface H^- production, caused by degradation of the Cs coating on the ionization surface. Following the arguments developed in reference 13 we further suspect that this process is driven by degradation of the rate Cs is released from the dispensers. A detailed discussion of the thermochemical reactions occurring within the Cs dispenser involving the mixture of Cs_2CrO_4, Al and Zr can also be found in reference 13. Briefly, Cs is released primarily through these reaction pathways.

$$\mathbf{4\ Cs_2CrO_4 + 5\ Zr \rightarrow 8\ Cs\ (g) + 5\ ZrO_2 + 2\ Cr_2O_3}$$

$$\mathbf{6\ Cs_2CrO_4 + 10\ Al \rightarrow 12\ Cs\ (g) + 5\ Al_2O_3 + 3\ Cr_2O_3}$$

Theoretically, there is enough Cs loaded in each source to support ~700 standard cesiations, which should supply an ample surface coating for periods of time much longer

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than these experiments. It is therefore most likely these reactions are limited by the availability of Zr and Al rather than Cs_2CrO_4. Computational thermodynamic analysis reveals that at temperatures greater than ~250 C, Zr and Al will spontaneously react and form stable compounds with residual gases evolved from the source during initial out-gassing. Employing the residual gas analyzer, we observe that significant quantities of CO_2, O_2, N_2 and H_2O are released into the vacuum chamber during each increase in source duty-factor. Therefore, it is clear that the Cs collar must be maintained at temperatures below 250C, ideally as cold as possible, until the source has been conditioned (out-gassed) to full duty-factor before heating the Cs collar.

LATER ION SOURCE RUNS

Prior to beginning experimental runs 8 and 9, the source was conditioned at full duty-factor and RF power for several hours while maintaining the Cs collar temperature below 100C using cooling air. The residual gas analyzer was used to verify that out-gassing was complete. The source was then cesiated and operated in the same manner described for the earlier experimental runs. Experimental runs 8 and 9 both show an extraordinary beam persistence with time: mean beam attenuation rate decreased from an average of 5 mA/day (runs 1-7) to 0.4 mA/day (run 8 and 9) as a result of implementation of the new conditioning technique. Fig. 3 shows beam currents in excess of 30 mA were maintained for 16 days of continuous operation at full duty-factor. The run was terminated due to a puncture through the ion source antenna.

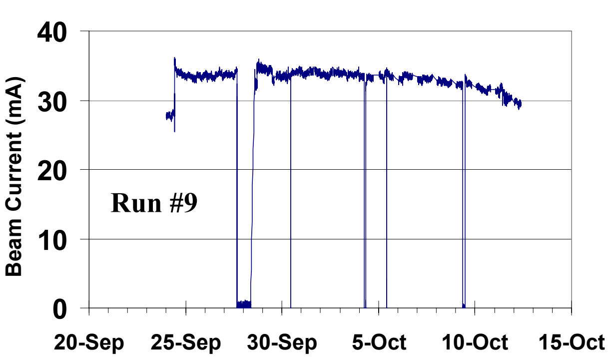

Figure 3: Beam current record of experimental run 9.

OUTLOOK

At low duty-factor (<<1%), the ion source continues to meet the commissioning goals of the SNS Accelerator with an availability of ~99%. At full duty-factor (7.4%), the new source conditioning procedure has resulted in an order-of-magnitude improvement in beam persistence, allowing delivery of beams in excess of 30 mA for ~16 days. We are now much closer to meeting the SNS operating goal of 38 mA for 21 days.

An aggressive ion source R&D program is being pursued with the goal of developing an ion source capable of meeting SNS operational and SNS power upgrade requirements (75-100 mA). New Cs collars have already produced beams of 70 mA peak / 60 mA average current at full duty-factor (7%) at the cost of an increased emittance [13,14]. A higher-power version of the external antenna employed in the DESY H^- source has also been designed and built [15].

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