Proceedings of the 2003 Particle Accelerator Conference

DEVELOPMENT AND STATUS OF THE SNS ION SOURCE

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Abstract

The ion source for the Spallation Neutron Source (SNS) is a radio-frequency, multicusp source designed to deliver 45 mA of H$^-$ with a normalized rms emittance of less than 0.2 π mm mrad to the SNS accelerator. The ion source—designed, constructed, and commissioned at Lawrence Berkeley National Laboratory (LBNL)—satisfies the basic requirements of commissioning and early operation of the SNS accelerator. To improve reliability of the ion source and consequently the availability of the SNS accelerator, we are undertaking a comprehensive ion source development program at Oak Ridge National Laboratory (ORNL). To date, this program has focused on design and development of internal and external ion source antennas having long operational lifetimes, development and characterization of efficient RF matching networks, simulation and measurement of the extracted ion beam and, optimization of the beam extraction and Cs systems. This report will outline progress made in some of these areas as well as summarize the current state of the SNS ion source discussing specifically source performance during front end re-commissioning at ORNL.

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 and is currently under construction at Oak Ridge National Laboratory (ORNL). Neutrons will be produced by bombarding a liquid Hg target with a 1.4-MW, 1-GeV proton beam produced using several types of linear accelerators and an accumulator ring [1,2]. In order to meet this baseline requirement, the ion source must deliver approximately 45 mA of H$^-$ within a 1-ms pulse (60 Hz) into a normalized rms emittance of 0.2 π mm mrad. SNS performance upgrades are being discussed which will require 3-5 MW of beam power and consequently demand higher beam currents from the ion source. This report discusses some highlights of our ion source development program as well as ion source performance during the re-commissioning of the front end at ORNL.

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. RF power (2 MHz, 20-50 kW) is applied to the antenna shown in the figure through a transformer-based impedance-matching network. 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. A heated 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. More details of this source design can be found in reference 3.

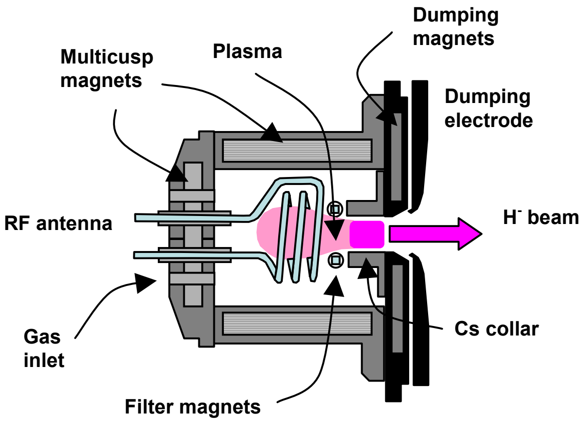

Figure 1: Schematic diagram of the SNS ion source.

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*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.

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RF ANTENNA DEVELOPMENT

The multicusp, RF-driven, positive/negative ion sources developed at LBNL have performed quite well in a wide variety of applications [4]. Most of these applications have involved pulsed, low duty-factor operation in which thinly coated (100- to 200-um) porcelain enamel coatings were sufficient to guarantee a long operational lifetime. The SNS ion source, on the other hand, requires long pulses (~1 ms) and high repetition rates (~60 Hz) as well as high peak RF powers (20-50 kW) and therefore tends to destroy these antennas rapidly, usually within a few hours of operation. In a collaborative effort between LBNL and ORNL, we began to improve the lifetime of this ion source component. Detailed accounts of this effort can be found in earlier work [5], and we will only summarize here.

Electromagnetic modeling has shown that a 1- to 2-kV RF potential develops across the length of the antenna because of its inductance. Large RF electric fields can develop between different parts of the antenna and between the antenna and the plasma chamber, since one leg of the antenna is grounded to the plasma chamber through a resistor. If the antenna coating is not sufficiently thick or has too large a dielectric constant the majority of this electric field will exist within the plasma sheath as opposed to within the insulating coating. Large electric fields in the plasma sheath accelerate charged plasma particles into the coated antenna, causing sputter ejection of the coating materials as well as vaporization of the coating material from localized heating. Eventually, a thin spot in the coating develops that enhances the electric field, driving the process until a hole is burnt through the coating. Once bare conductor of the antenna is exposed to the plasma, the plasma itself can conduct a significant portion of the RF current normally carried by the antenna and thereby greatly reduce the inductive power coupling to the plasma. This process can be greatly accelerated if a manufacturing defect already exists porcelain coating.

Quantitative models have been developed and applied to fusion plasmas to determine the fraction of a given electric field that exists within the plasma sheath, versus the field inside a dielectric wall material [6]. Using the plasma parameters of the SNS source and material properties of the porcelain enamel coating, it has been shown that essentially all of the electric field within the plasma sheath can be eliminated provided the following two conditions are met [6]. First, the coating is sufficiently thick, greater than 0.5 mm, several times the thickness of the original coating. Second, the dielectric constant of the porcelain is reduced by removal of the TiO_2 (K=86) component from the porcelain mixture.

Based on these calculations, a local company [7] developed a multi-layer coating technique to achieve the specified coating thickness and composition. Since TiO_2 is added to porcelain enamel mixtures purely as a color pigment with no structural importance, it was easily eliminated from the mixture resulting in a coating that appears clear. This approach has yielded coatings as thick as 1 mm which was achieved through the successive application of ~10 enamel layers. Increasing the number of layers also improves antenna lifetime by reducing the chance that a single layer defect will cause an electric breakdown through the coating.

To date antennas fabricated in this fashion have allowed the successful commissioning of the front end of the SNS at LBNL (~500 hours of operation) and again at ORNL (~1000 hours of operation) [8]. In addition to these accelerator-commissioning activities, which have generally required low duty-factor operation, we have also performed several high duty-factor lifetime tests. On one occasion, the source operated continuously for 107 hours with ~25 kW of applied RF power at the full 6% duty factor with no visible damage to the antenna observed. During the last few hours of the test, a ~25 mA beam was extracted from the source. Another such test also occurred at LBNL on the front-end system, where the source was operated for 125 hours at 2-3% duty factor, again producing ~25 mA with no antenna damage visible.

To ensure an adequate ion source lifetime at the nominal SNS beam current and duty factor, in the absence of specific lifetime tests, we have developed a contingency strategy for coupling RF power into the source: use of an external antenna. This approach is similar to that employed at DESY for their very low duty factor application [9]. To date, thermal and mechanical finite-element analysis has been performed on an Al_2O_3 plasma chamber to determine an optimal design. One such design, shown in Fig. 2, was developed in conjunction with designers at ISI Corporation. The design features an alternative ion source backflange where the helical antenna is submerged in de-ionized water surrounding an Al_2O_3 plasma chamber. This system is currently under consideration for development.

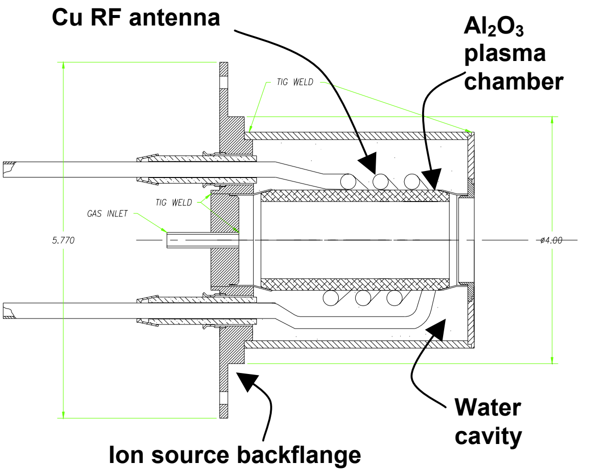

Figure 2: Initial design of an external antenna for the SNS ion source.

SOURCE PERFORMANCE

The SNS front end was recommissioned at ORNL from Nov 5, 2002, to Jan 31, 2003. The ion source performed quite well over this period and allowed accomplishment of most of our commissioning goals [8].

Initially, a beam-intercepting flag (biased to +300V to suppress secondary electrons) was installed just downstream of the extractor electrode and was used for initial ion source check out as well as operator training. Beam currents as high as 35 mA were produced during this early commissioning period. Fig. 3 shows the dependence of the ion current, intercepted by the flag, on the applied RF power for an un-cesiated source (squares) and after 1 successful cesiation of the source (diamonds). Source cesiation was accomplished by raising the temperature of the 8 Cs dispensers to ~550 C for ~1/2 hour and then maintaining a collar temperature of ~275 C.

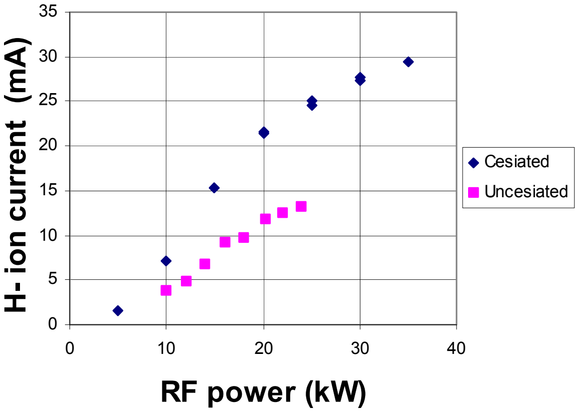

Figure 3: Ion current versus applied RF power from both cesiated and uncesiated sources.

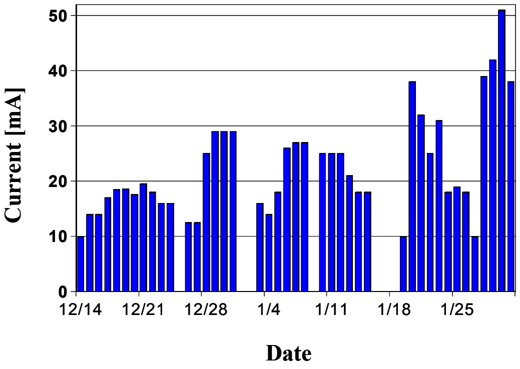

Figure 4: Typical beam currents produced during front-end commissioning at ORNL.

On Dec 14 we began injecting beam into the front-end system [8]. Fig. 4 shows typical beam currents measured over the accelerator-commissioning period by current transformers located near the entrance and exit of the medium-energy beam transport (MEBT). Since most of our commissioning tasks did not require large beam currents, we ran at modest currents levels of 15- to 30-mA for much of the commissioning period.

The commissioning period also served as a shakedown of the front-end system delineating weaknesses. The ion source and low-energy beam transport (LEBT, between the ion source and RFQ) systems were available 68% of the time. Much of the down time was attributed to mechanical failures of the LEBT, problems with the ion source RF amplifiers induced by high-voltage sparks, and not having a readily available backup source. Most of these problems have been corrected over the last several months. Near the end of this period when we aimed for higher beam currents, consistent with the commissioning schedule, we were able to achieve currents in excess of 51 mA from a newly cleaned source with fresh Cs operating at higher collar temperatures (300 C) than were maintained during earlier operations.

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