THE DEVELOPMENT OF A HIGH-POWER, H^- ION SOURCE FOR THE SNS* BASED ON AN EXTERNAL ANTENNA

R. F. Welton, M. P. Stockli, S.N. Murray, SNS, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN, 37830-6471
J. Peters, Deutsches Elektronen-Synchrotron (DESY), Notkestra e 85, 22607, Hamburg, Germany

Abstract

The ion source originally developed for the Spallation Neutron Source* (SNS) is a radio frequency, multi-cusp H^- source, which utilizes an internal antenna immersed within the source plasma. To date, the source has been utilized successfully in commissioning of the SNS accelerator delivering 10 - 40 mA with duty-factors of ~0.1% for periods of several weeks. In the near future, the SNS facility will require beam currents of ~40-60 mA at ~7% duty-factor. Tests have shown that the internal antenna is susceptible to failure at this high duty-factor. Currently, two ion sources are being developed which feature ceramic plasma chambers surrounded by an external antenna. The first is a simple, prototype source allowing beam extraction experiments to be performed at low duty-factor. This source has already produced considerably higher H^- beam currents than the original SNS source when both are operated without Cs. The second ion source is a high-power version which features an integrated metallic Faraday shield - magnetic multicusp structure and is designed to operate at full duty-factor. Details of this design and the measured performance of the prototype source are discussed.

INTRODUCTION

High-brightness H^- ion sources are widely used in large accelerator facilities which utilize charge-exchange injection into circular accelerators or storage rings [1]. One such facility, the U.S. Spallation Neutron Source (SNS)* employs a Radio-Frequency (RF), multicusp ion source featuring a porcelain-coated Cu antenna immersed in the plasma volume [2, 3]. To date, the source has been utilized successfully in commissioning of the SNS accelerator delivering 10 - 40 mA with duty-factors of ~0.1% for periods of many weeks. In the near future, the SNS facility will require beam currents of ~40-60 mA at ~7% duty-factor. During continuous testing at this duty factor the internal antenna was found to be susceptible to damage, limiting source lifetime [4].

Although recent advances in antenna coating technology [5] have resulted in substantial performance improvements [6] especially for low duty-factor plasmas, it is doubtful that internal antennas can ever be truly competitive with external antenna systems [7]. The DESY ion source employs an aluminum oxide cylinder to separate the plasma from the RF-antenna [8]. Operating at comparable RF pulse power-levels to the SNS requirement but at less average RF power (pulse width: 100-200 μs; repetition rate: 6 Hz) the system has demonstrated over 25,000 hours of maintenance-free operation delivering 30-40 mA of H^- current.

Based on this success, we have designed, built and tested a simple external antenna module which replaces the internal antenna and backflange of the plasma chamber in the original SNS ion source. This configuration allows operation of the SNS ion source with an external antenna preserving the extraction region of the plasma chamber (filter magnetic field and Cs collar) and the beam extraction system (extractor electrode and electron dumping system) [3]. The performance of this source operating with an air and liquid cooled plasma chamber, a metallic Faraday shield and a plasma gun is presented. Based on these findings, a high-power, external antenna ion source has been designed employing Finite Element Analysis (FEA).

PROTOTYPE SOURCE

The details of the design of the external antenna module have been described previously [9]. Briefly, the cylindrical ceramic plasma chamber is constructed from high-purity Al_2O_3 (inside ϕ=4.8 cm, l=10 cm and wall thickness = 0.6 cm) and secured by the compression of two o-rings. A 6-turn, helical, water-cooled antenna constructed from copper tubing (ϕ =5 mm) surrounds the plasma chamber. The antenna cavity is cooled by flowing air or liquid through opposing inlet and outlet ports which penetrate the back-flange. There is no magnetic confinement employed with this source. Beam-pulses are produced with the application of power from a pulsed 2 MHz (P=80 kW max) RF-generator to the antenna through a matching network. Plasma density and ignition time are enhanced by the use of a continuously streaming plasma gun injecting the main plasma chamber from the rear of the source. The gun is based on a simple DC glow discharge and is described elsewhere in these proceedings [10]. The outlet aperture assembly of the original SNS ion source which contains a transverse magnetic dipole (150-300 Gauss) filter field and a cylindrical collar (ϕ=15mm, l=13mm) surrounding the outlet aperture (ϕ=7mm) has been employed. The collar contains eight cesium chromate dispensers which release Cs when heated by the plasma to ~550 C [6].

Beam extraction experiments were performed on the ion source test stand at the SNS [11]. Beam current was measured at the exit of an electrostatic Low Energy Beam

* ORNL/SNS is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725

Transport (LEBT) identical to the one employed in the SNS accelerator by a toroidal current transformer. The extracted H^- beam current versus RF power is plotted in Fig. 1 (squares) for the source employing air cooling and with the plasma gun deactivated. Low duty-factor pulses (200 µs and 10 Hz) are plotted to allow the direct comparison of effect of employing each plasma chamber cooling method on overall beam current. For comparison, the original SNS ion source with an internal antenna will produce no more than 10-20 mA of H^- without Cs. No Cs was employed in these experiments. Recently, the calibration of our RF power system was corrected using a high-power 50 Ω attenuator and network analyzer. Earlier data likely underestimated RF power by a factor of 1.3-2.

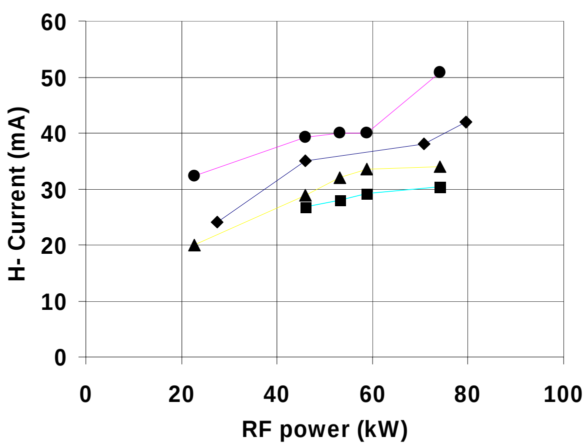

Figure 1: Extracted H^- beam current versus applied RF power: squares – air cooling, plasma gun deactivated; circles – air cooling, plasma gun activated; triangles - liquid cooling, plasma gun activated; diamonds – air cooling, plasma gun activated, Faraday shield inserted (Fig. 2).

A dramatic ~50% increase in the extracted H^- beam current was observed (circles in Fig. 1) when the plasma gun was activated. Attempts to increase the plasma duty factor of the air-cooled source resulted in two catastrophic failures of the plasma chamber likely caused by thermal stress. Both failures occurred when the average RF power was increased to 2.4 kW (duty factor = 5.4%) which was insufficient to heat the collar to the cesiation temperature of 550C.

Several plasma chamber cooling and shielding options were explored using this prototype source for possible incorporation into the design of the high-power source. First, liquid cooling was investigated by flooding the antenna cavity with flowing de-ionized water and Fluorinert [12]. The de-ionized water reduced the beam current to only a few mA and Fluorinert reduced beam current ~25%. Inserting a mock, un-cooled, aluminum Faraday shield (see Fig. 2) into the plasma chamber reduced the beam current only ~8%. We therefore chose to incorporate a similar Faraday shield in the high-power source design.

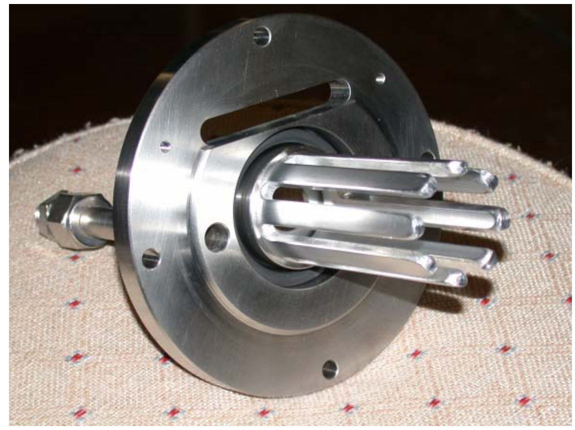

Figure 2: Metallic Faraday shield and backflange inserted into the ceramic plasma chamber of the prototype ion source.

Long-pulse operation was investigated using liquid cooling (Fluorinert) of the plasma chamber. The LEBT was removed for these studies and beam collected in a suppressed Faraday cup located ~3 cm from the extractor electrode. High-quality, 33 mA H^- pulses, 1.23ms in length, were extracted from the source showing a good ~50 µs rise-time and minimal ~5% droop.

Fig. 4 shows the extracted H^- beam current as a function of the electric field at the outlet aperture varied by adjustment of the electron dumping electrode potential and computer electrostatic simulation. These data suggest that much higher beam currents could be accessible if a 3-5 kV/mm extraction system such those employed in other H^- ion sources (DESY, JAERI, SSC, Gumman, etc.) was utilized [13].

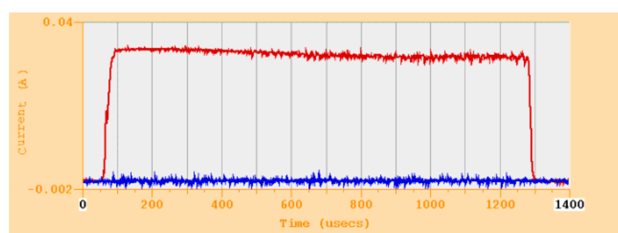

Figure 3: Example H^- pulse (33 mA, 1.2 ms in length) extracted from the prototype ion source.

HIGH-POWER SOURCE

Information gleaned from experience with the prototype source as well as from finite element modeling (FEA) (fluid, thermal, structural, electromagnetic and particle simulation) has led to the design of the high-power external antenna ion source shown in Fig. 5 [14].

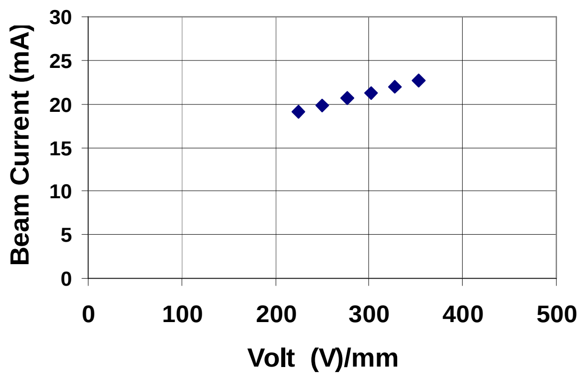

Figure 4: Beam current plotted against electric field strength at outlet aperture adjusted by varying the extraction potential (see text).

The design is based on achieving magnetic plasma confinement within a Faraday shield similar geometrically to the one successfully tested in the prototype source. The plasma diameter is approximately 4.8 cm, the same as in the unshielded prototype source. Each 'finger' of the Faraday shield contains a water cooling passage and a set of multicusp magnets. Fig. 6 shows that an n=12 multicusp magnetic configuration can be achieved using only the six fingers of the Faraday shield. Orientating the magnetization axis of each magnet as shown in the figure and shaping the pole faces properly, the flux linkage between adjacent magnets and opposite poles on the same magnet can be made approximately equal, doubling the multiplicity of the magnet array. Using high-energy product (MGOe ~ 50) Nd-Fe-B magnets, the maximum field at the wall of the multicusp finger can be made B~2500 G while being effectively zero over ~2 cm in the center of the plasma chamber.

The Faraday shield – multicusp array is surrounded by a large high purity Al_2O_3 plasma chamber (inside ϕ=7.6 cm, l=20 cm and wall thickness = 0.6 cm).

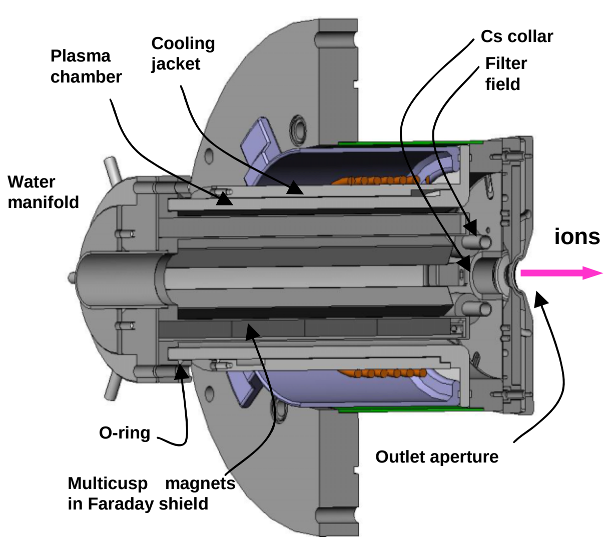

Figure 5: The high-power external antenna source.

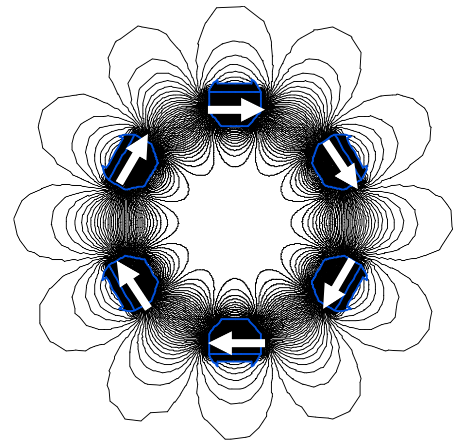

Figure 6: Magnetic field pattern which results from the multicusp configuration used in the high-power source.

The large surface area of this chamber significantly reduces the plasma power density loading the surface. The chamber is surrounded by a Delrin air cooling jacket. Coupled fluid-thermal-mechanical FEA shows this system can easily accommodate the 3.5 kW heat load expected from full duty-factor operation. The antenna is protected from arcing by using polyolefin heat-shrink tubing (~20 kV isolation). The design also allows easy interface with a plasma gun as well as a high-field extraction system.

REFERENCES

[1] T. Mason, Physics Today, AIP Press, p.44 May 2006.

[2] www.sns.gov

3R. Keller, et al, Sci. Instrum. **73** 914 (2002).

[4] R.F. Welton, et al., Proceedings of PAC05, Knoxville, TN, USA.

[5] R. F. Welton et al., Rev. Sci. Intrum. **73** 1008 (2002).

[6] R.F. Welton, et al., Proceedings of the Tenth International Symposium on the Production and Neutralization of Negative Ions and Beams", AIP Conf. Proc. 763 (2005) p 296.

[7] J. Peters, Proceedings of the EPAC02, Paris, France.

[8] J. Peters, Proceedings of the LINAC98, Chicago, Il, USA.

[9] R. F. Welton et al., Rev. Sci. Intrum. **77,** 03A508 (2006).

[10] R.F. Welton et al., these proceedings.

[11] R.F. Welton, et al., Rev. Sci. Instrum. **75** 1793 (2004)

[12] FC-70, 3M Corporation, 3M Center, St. Paul, MN, 55144.

[13] D.P Moehs, at al. IEEE Trans. Plasma Sci. **33** 1786 (2005).

[14] SOLIDWORKS, COSMOS, 300 Baker Ave, Concord, MA, 01742; SIMION, Scientific Instrument Services, 1027 Old York Rd., Ringoes, NJ 08551; PBGUNS, Thunderbird Simulations, 626 Bradfield Dr. Garland, Texas 75042.