DEVELOPMENT OF THE SNS EXTERNAL ANTENNA H^- ION SOURCE

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Abstract

The U.S. Spallation Neutron Source (SNS) is an accelerator-based, pulsed neutron-scattering facility currently in the process of ramping up neutron production. To meet present and future beam current and reliability requirements we are developing an RF-driven, H^- ion source based on a ceramic aluminium nitride (AlN) plasma chamber surrounded by an external RF antenna. This report recounts the design of the prototype source, describes the Cs collar variations tested, enumerates recent modifications made to the source to prepare a production version, and summarizes the results of runs on the SNS test stand and Front End (FE) of the SNS accelerator. Up to ~100 mA unanalyzed beam currents (60Hz, 1ms) have been measured on the SNS ion source test stand, and up to 42mA have been successfully accelerated by the RFQ on the SNS front-end at lower RF power.

INTRODUCTION

To exceed 1 MW of beam power on target by 2010, the ion source is required to deliver an H^- linac beam current of 38 mA, 1.0 ms in length with a repetition rate of 60 Hz (~6% duty factor). Upgrading the facility to 3 MW requires H^- linac beam currents of 59 mA with a normalized rms emittance not exceeding 0.35 π mm mrad. Presently, the SNS uses a RF-driven H^- ion source developed at LBNL which features an internal porcelain-coated antenna. In FY2008 ~25% of antennas developed defects during operation. This fraction was drastically reduced during run 2009-1 when the RF power was reduced while the beam was increased - partly by increasing the e-dump voltage [1]. Replacing the ion source every 3 weeks has so far largely eliminated downtime due to antenna defects. Further improving reliability as duty-factor is ramped to 6% and run periods are extended suggests external antenna sources should be developed.

PROTOTYPE SOURCE DESIGN

The SNS external antenna source has been described previously [2]. Briefly, it consists of a flanged, high-purity, AlN ceramic plasma chamber (ϕ=6.8 cm; length: 18 cm; wall thickness: 0.7 cm). Computationally, the chamber was found to be capable of withstanding isotropic heat loads of 100 kW at 7% duty factor while maintaining a thermal stress safety margin of ~2x using coupled fluid dynamic, heat transfer, and thermal stress Finite Elemental Analysis (FEA). The outer surface of the AlN chamber is directly water-cooled by a polycarbonate serpentine cooling jacket consisting of a single 3.3 x 9.6 mm water passage flowing ~1.5-2.7 gal/min of de-ionized water. The cooling jacket has also been computationally designed to have a safety factor of ~2x at full water pressure using similar FEA techniques. As seen in Fig. 1, a two-layer, 4.5-turn water-cooled Cu antenna was designed to surround the jacket in the forward-most position. Three layers of polyolefin heat-shrink tubing protect the antenna windings from ~12kV of peak RF voltage. Plasma confinement is provided by 8 multicusp magnets surrounding the chamber, and the source backflange provides mounting for a plasma gun for RF plasma ignition [2]. A ~280G magnetic filter field screens hot electrons from the outlet region of the source. Cs is delivered to the source through a collar surrounding the outlet aperture (see Fig. 2). Three collar configurations were employed in these experiments.

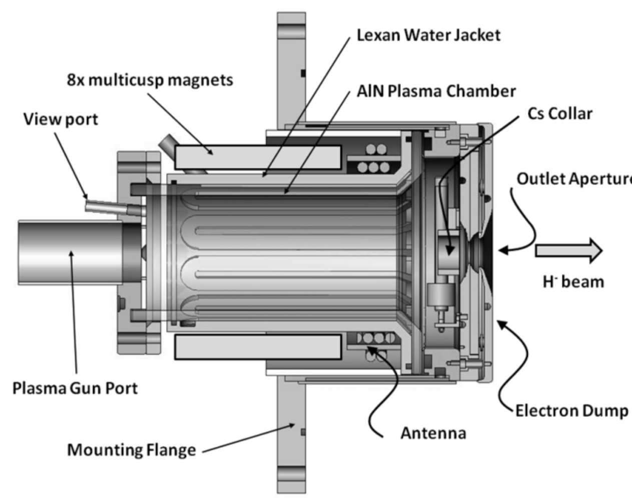

Figure 1: Schematic diagram of the SNS External Antenna Source (detailed view of collar shown in Fig. 2).

CS COLLAR CONFIGURATIONS TESTED

Figure 2 shows the three collar configurations tested: (i) Cs-chromate dispensers and a conical-40^{o} Mo ionization surface, (ii) Elemental Cs system used with a conical-30^{o} Ni ionization surface and (iii) Cs-chromate dispensers used with a conical-30^{o} Ni ionization surface with similar geometry to (ii). The Cs chromate systems employ <30mg of Cs distributed among 8 dispensers located within the collar wall, while the elemental system is fed from an external Cs reservoir containing 0.2-1g Cs charges. Note the ionization surface in (i) is located ~1mm from the downstream face of the outlet aperture versus ~0.5 mm for configurations ii and iii. Selected results are shown in Table 1.

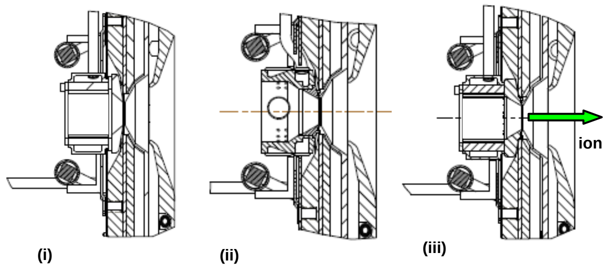

Figure 2: Cs collar configurations tested.

PRODUCTION SOURCE CONFIGURATION

After configuration (i) produced 40 mA MEBT beam current in July 2008 for several hours, this configuration was selected as the baseline source for run 2009-2, which started 3-3-09. Four production sources were built up, while several modifications to the prototype source were implemented: (1) replace Cu cathodes with Mo in plasma gun to reduce Cu coating on AlN chamber; (2) replace Ta heat shield with SS version to eliminate Ta-H_2 embrittlement; (3) modify cooling jacket to eliminate leaks by changing water connections to stainless steel and re-shaping and annealing the polycarbonate (FEA shows factors-of-safety increase of 2$\rightarrow$5); (4) air-cooling multicusp magnets, which showed excessive heating after one run; (5) replace SS-Cu braze with Cu coated SS in source body to eliminate a water leak. The changes were implemented for each source employed during the 2009-2 run: time constraints did not permit full 3-week lifetime tests of the final configuration on the test stand before the start of the run.

PERFORMANCE OF THE PRODUCTION SOURCE

Table 2 shows measured performance of each production source on the test stand and SNS FE. In preparation for run 2009-2, four sources were tested for a few days on the FE just before the start of the run. Run 2009-2 started with scheduled source replacements after one week of accelerator studies and again after a brief production run.

As shown in Table 2, the external antenna source normally met the 35mA MEBT current requirement set for the 2009-2 run. Shortly after a cesiation the requirement could be met with an antenna current in the range of 480 to 540 A pk-pk. Subsequently, the drooping performance required ramping up the RF power to yield 600 A pk-pk antenna current. This is in contrast to the LBNL baseline source, which often exhibits a performance free of degradation within the observed 3-week periods [1]. The difference may be due to poisoning of the cesiated surface through materials emitted by the AlN chamber or by the plasma gun. Potential mitigations may require frequent re-cesiations, which could compromise the performance of the RFQ and/or LEBT.

After starting the 3-week neutron production source cycle, the sources experienced 2 antenna failures, 2 plasma gun failures, and a water leak which required 5 unscheduled source replacements within less than 4 weeks. This significantly exceeds the ~1 unscheduled source replacement within 19 weeks required for the LBNL source [1]. Availability requirements mandated the reimplementation of the LBNL source for the remainder of run 2009-2.

CONTINUED SOURCE DEVELOPMENT AND THE PATH FORWARD

This experience provided us with a focused list of problems which need to be addressed before we continue use of this source on the SNS accelerator: (i) plasma ignition, (ii) antenna reliability (iii) water jacket integrity and (iv) source assembly practice. Once each of these points are addressed and solutions implemented, schedules will be adjusted to allow full lifetime tests (>3 weeks) to occur on the test stand. Each issue will be discussed below.

(i) Plasma ignition- Some Mo cathodes employed in the plasma gun (production source) show an unexpected aging process which seems to render ignition impossible after about a week of continuous operation.

Table 1: Performance Summary of Prototype Sources Tested with Different Cs Collars on the SNS Test Stand

Run #/ Date	Collar Configuration	Type	Ionization surface	Maximum beam current / RF power	Sustained beam current / RF power / days of operation
run-2 1/24/08	Elemental collar	ii	304 SS	60mA/ 50kW	>40mA / ~35kW / ~3 weeks
run-4c 6/17/08	Elemental collar	ii	Mo	81mA/ 48 kW	>50mA / ~45kW /~3 days
run-5 6/20/08	Chromate collar	i	Mo	55mA/ 56 kW	>40mA / ~35kW /~3 days
run-6 6/28/08	Elemental collar	ii	Ni	95mA/ 52 kW	>60mA / ~35kW / ~3 days
run-9 11/13/08	Chromate collar	iii	Ni	87mA / 60kW	>60mA / ~45kW / ~1 week

Table 2: Selected Performances of Production External Antenna Sources

Ion Source #	Test stand performance Beam current / RF power / antenna current / duration	Reported beam current measurements on FE: date / antenna current / RF power
ext1	Only tested with Ni collar	2-12-09: 40mA / 540A
	TS-run-9 (11-13-2008): 60mA / 45kW / 600A / ~1 week	2-13-09: 35mA / 520A / ~27kW
		2-16-09: 38mA / 520A / ~27kW
		3-3-09: 35mA /540 A / ~26kW
		3-16-09: 35mA / 480 A
		4-6-09: 36mA / 520 A
		4-19-09: 35mA / 540 A
ext2	TS-run-11 (12-12-2008): 55mA / 52kW / 600A / ~1 week	2-20-09: 33mA /520A/ ~27kW
		2-23-09: 35mA / 540A / ~30kW
	TS-run-13 (1-2-2009): 55mA / 48kW / 600A / ~2 weeks	2-23-09: 38mA / 560A
		3-2-09: 35mA / 540A / ~26kW
		3-9-09: 32mA /560A / ~30kW
		3-11-09: 35mA / 560 A
		3-16-09: 35mA / 480 A
		3-25-09: 36mA / 540 A
		4-13-09: 35mA / 520 A
ext3	TS-run-12 (12-23-2008): 55mA / 63kW / 680A / ~1 week	2-27-09: 35mA /520A / ~27kW
		3-1-09: 33mA / 520A / ~27kW
		3-11-09: 35mA / 520A/ ~27kW
		4-8-09: 36mA / 580A
ext4	TS-run-14 and 15 (2-12-2009): 47mA / 40kW / 510A / 10 days	Not yet tested on FE

The Cu cathodes (prototype source) do not show this effect but do seem to inject excessive sputtered Cu particles into the ion source which could potentially cause problems.

The Cu cathodes have demonstrated operation for >4 weeks. The use of other cathode materials which exhibit minimum sputtering, quantifying their lifetimes and performance using a 4-port stand-alone test stand is being planned. In addition, the SNS RF group is also developing a low-power, continuous 13MHz RF system which was successfully employed in the baseline LBNL source.

(ii) Antenna reliability- Many of the antennas used in the production runs were not wound in the 2-layer isolated format and were recycled from run-to-run. The failed antennas started to arc between the first and the last turn of the coil where the RF electric fields were greatest, likely exceeding the dielectric breakdown strength of air. Inserting a 2.4-mm-thick Teflon ring between the inner and outer layer of windings seems to have resolved this problem. Currently we are also developing an epoxy-potted version of this antenna.

(iii) Water jacket integrity - In general, the annealed polycarbonate cooling jackets have resulted in a considerable reliability improvement over the earlier versions and the leak experienced during the run was likely due to assembly issues. To improve dimensional stability and overall reliability still further, we have designed and are fabricating jackets from PEEK material. FEA analysis shows a factor of safety improvement from 5→9.

(iv) Source assembly practice- Like any accelerator component quality control is of paramount importance. To improve overall quality control we are implementing written assembly procedures specifying gaps, torques and components, and itemized build checklists. In addition several assembly fixtures have also been created.

These efforts will be supplemented by engineering evaluations aimed at improving the overall robustness of the source.

ACKNOWLEDGEMENTS

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REFERENCES

[1] See, for example B.X. Han, S. N. Murray, D. Newland, T. R. Pennisi, M. Santana, R. Welton, and M. P. Stockli, these Proceedings.

[2] R.F. Welton, M.P. Stockli, S.N. Murray, D. Crisp, J. Carmichael, R.H. Goulding, B. Han, O. Tarvainen , T. Pennisi, M. Santana, AIP Conf. Proc. #1097 (American Institute of Physics, New York, 2009) pp. 181-190.