INITIAL TESTS OF AN ELEMENTAL CS-SYSTEM WITH THE SNS ION SOURCE

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Abstract

The Spallation Neutron Source* (SNS) facility employs an RF-driven, Cs-enhanced, multi-cusp H^- ion source. To date, the source has been successfully utilized in commissioning the SNS accelerator and in early operations of the facility, producing beam currents of 10-40 mA with duty-factors of ~0.1 %. In the near future, the ion source will be required to inject 40-60 mA of beam current into the linac with a duty-factor of ~7%. We are therefore investigating methods to simultaneously increase the beam current, duty-factor and reliability of the SNS ion source. Presently, Cs is dispensed within the source using cartridges containing a compressed powder mixture of Cs_2CrO_4, Al and Zr loaded into a cylindrical collar surrounding the outlet aperture. The source is cesiated by briefly increasing the temperature of the Cs_2CrO_4. Initially, this process increases the H^- beam current significantly but the beam soon decays to a more modest level of enhancement. The degree and duration of H^- beam current enhancement can vary considerably between ion sources (not reproducible) and can only be repeated 1-3 times in a given source before the Cs is depleted and the source needs to be replaced. This is especially problematic during high duty-factor operation. This report describes the design of an elemental Cs system incorporating an external elemental Cs reservoir (based on the proven Fermilab design), a directly heated Cs transfer line, a Cs injection collar and a temperature-controlled conical ionization surface. The results of the first experiments performed with this system are reported.

INTRODUCTION

The Spallation Neutron Source (SNS) is a large user facility dedicated to the study of materials by neutron scattering and is currently beginning operations at Oak Ridge National Laboratory (ORNL) [1,2]. To date, the source has been successfully utilized in commissioning the SNS accelerator and in early facility operations producing beam currents of 10-40 mA with duty-factors of ~0.1 %. In the near future, beam power on target will be increased to 1.4 MW and the ion source will be required to inject ~40 mA of H^- (pulse length = 1 ms, repetition rate = 60 Hz, 6% duty-factor) into the LINAC. Later, the SNS power upgrade project will require the injection of ~60 mA at the same duty-factor [3]. In order to prepare for delivery of these beams we have performed extensive off-line tests of the original SNS ion source configuration at the full required duty-factor for multi-day continuous run-periods on the SNS ion source test stand [4].

The original SNS ion source was designed, developed and tested at Berkeley National Laboratory (LBNL) and has been described previously in Ref. 5. Briefly, the source plasma is confined by a multicusp magnetic 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, 20-80 kW) is applied to a 2 ½ turn porcelain-coated antenna centered in the plasma chamber [6]. A magnetic dipole (150-300 Gauss) filter separates the main plasma from a smaller H^- generation region where low-energy electrons facilitate the production of large amounts of negative ions. This region of the source is shown in Fig. 1. An air heated/cooled collar, equipped with eight cesium dispensers manufactured by SAES Getter Corporation, surrounds the outlet aperture of the source [7]. Each dispenser (dimensions: 12x1.4x1 mm) contains a total of 5.2 mg of Cs in the form of a compressed powder mixture (17% Cs_2CrO_4, 70% Al and 13% Zr).

During an ion source cesiation, the temperature of the Cs collar is briefly elevated to ~550 C by interrupting cooling air flow to the Cs collar, thereby allowing plasma heating.

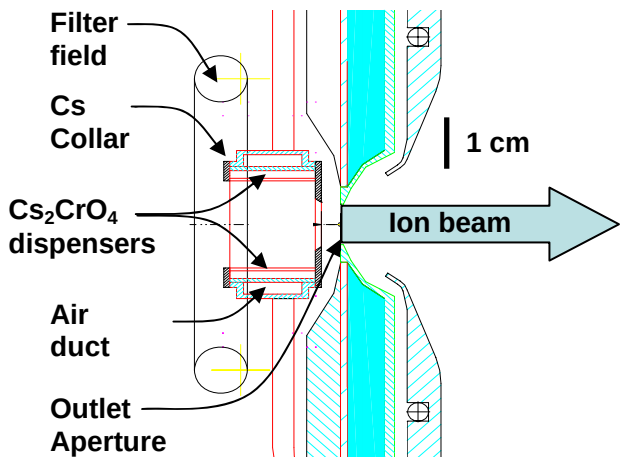

Figure 1: Schematic diagram filter-field, Cs collar and outlet aperture of the original SNS ion source.

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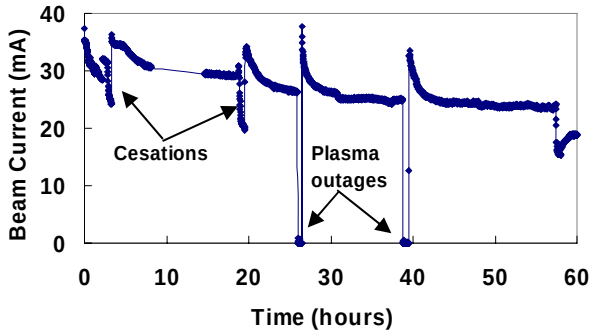

Figure 2: Typical behavior of the original SNS ion source. Extracted H^- beam current is plotted against time showing the effect of cesiations and plasma outages.

This temperature is held for 30 min. and then cooling air is restored to return the collar to the nominal operating temperature of 200-300 C. Fig. 2 shows the effect of this process on beam current: during a cesiation beam current falls significantly, to nearly uncesiated values. Once the collar is restored to nominal operating temperature a considerable H^- enhancement is initially observed, but decays in ~8h to a more modest level of enhancement which slowly decreases with time. The degree and duration of H^- beam current enhancement can vary considerably between ion sources and individual cesiation attempts in the same source. Each source can accommodate only 2-3 cesiations before the Cs is depleted, a process which often limits lifetime [4]. Recently, the development of a new cesiation procedure has decreased the overall attenuation rate of the beam but each of the other issues remain [8].

Since the above cesiation technique involves a 'dosing' of the source with Cs and the subsequent collection of Cs returning to the collar, the flux cannot be sufficiently controlled to guarantee optimum coverage. The elemental Cs system will allow sufficient control of Cs fluxes to insure optimal coverage (minimal surface work function) and consequently a higher source efficiency [4]. By comparison the elemental system should also be essentially immune from poisoning effects of residual gases [4] and carry a much greater supply of Cs than the original system. These qualities should completely decouple the Cs system from ion source lifetime limitations. Reproducibility should also be tremendously enhanced.

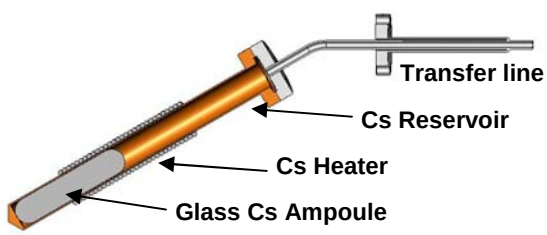

Figure 3: External Cs reservoir and directly heated transfer line.

THE ELEMENTAL CS SYSTEM

Fig. 3 shows the external Cs reservoir and heated transfer line. The reservoir is constructed out of Cu which is sufficiently malleable to serve as the gasket material for the conflate flange of the transfer line and allow the glass ampoule containing Cs to be crushed after the system is baked-out under vacuum. The reservoir is nearly identical to one employed at Fermilab which has been in service for many years [9]. The reservoir is heated to temperatures of 170-210 C by an external Thermocoax wire heater (ϕ=1.5 mm, unwound length=4.3 m, 26Ω) [10].

The Cs reservoir is affixed to a transfer line which delivers Cs to the injection collar shown in Fig. 4. The line consists of a ϕ (o.d.)=4.8 mm thin-walled stainless steel tube and is designed to operate with a minimum temperature of 300 C. The portion of the transfer line internal to the vacuum chamber is heated directly by the RF plasma and therefore does not require additional heating. The external portion, shown in Fig. 3, penetrates the vacuum chamber wall and is heated by flowing ~35 A (0.7 V) of AC current from an external supply along the tube wall of the transfer line. The current is returned to the power supply through a concentric ϕ (o.d.)=8mm stainless steel tube (also shown in Fig. 3) which is joined to the conflate mounting flange. The tube is designed to operate with a flat temperature profile of ~300C when driven with the above currents. The external and internal (partially shown in Fig. 4) transfer lines are joined with a threaded Macor coupler.

Cs, effusing through openings in the Cs injection collar shown in Fig. 4, is directed to the ionization cone which surrounds the source outlet aperture. The ionization cone is independently temperature controlled (20-500C) using heating/cooling air flow and thermal isolation from both the outlet aperture and Cs injection collar. The ionization surface has a conical shape to simultaneously allow plasma bombardment and extraction of surface-produced H^-. The Cs injection collar is heated by plasma heat flux to temperatures greater than 300C.

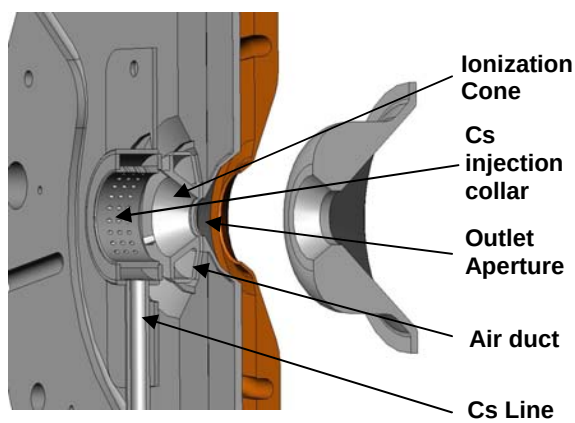

Figure 4: Cs injection collar, ionization cone and outlet aperture.

Cs leaves the injection collar through a series of 60 x ϕ=0.75 mm openings spaced in such a way as to uniformly paint the ionization cone with the effusing Cs. The Cs injection collar and ionization cone together have approximately the same external dimensions as the original Cs collar shown in Fig. 1.

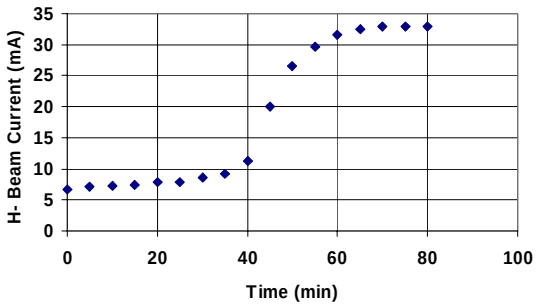

Figure 5: Extracted H^- beam current versus time as the Cs reservoir was set to a temperature of 185 C. H_2 flow: 45 SCCM and RF power: 35kW.

BEAM EXTRACTION MEASUREMENTS

Beam extraction measurements were performed on the SNS ion source test stand [4] with the Low Energy Beam Transport (LEBT) section removed. Beam was extracted at 65kV and intercepted in a large Faraday cup located ~3 cm downstream of the extractor electrode which is shown in Fig. 4. All measurements were performed with a beam pulse length of 1.2 ms and repetition rate of 10 Hz. We limited the repetition rate to 10 Hz due to excessive plasma heating of the internal Cs transfer line. This will be better shielded from the plasma in subsequent ion source tests. The Cs reservoir, transfer line and ion source were heated to their operating points prior to breaking the glass ampoule to insure thorough out-gassing of the system. A Residual Gas Analyzer (RGA) was employed to monitor progress. The ampoule was then broken using a C-clamp and the reservoir temperature was raised to 185 C while the transfer line was maintained at ~300C.

The response of the H^- beam current as a function of time is plotted in Fig. 5. Fig. 6 shows the extracted H^- pulse shape exhibiting little droop and a fast ~ 50 μs rise time. The ion source was run continuously for several days under these conditions and no H^- beam current overshoot or attenuation was observed.

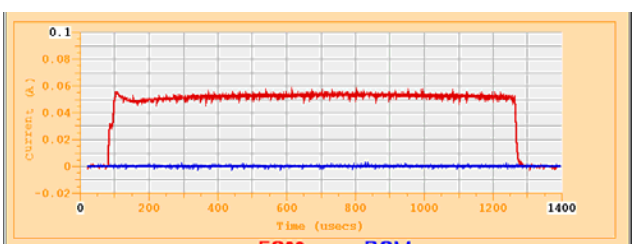

Figure 6: Extracted H^- beam pulse profile showing ~50 mA pulse average beam current.

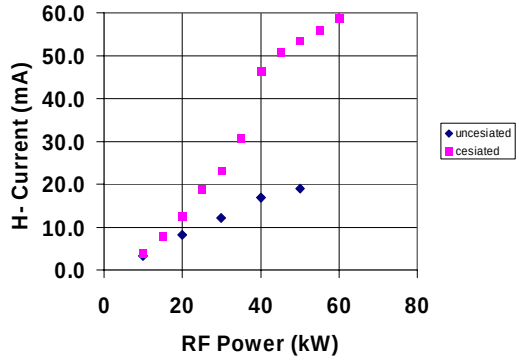

Figure 7: Extracted H^- beam current versus applied RF power. Scans made before and after cesiation.

After the initial cesiation, we observed little dependence of the H^- beam current on temperature of the ionization cone (30-400C) or on Cs reservoir temperature (170-205 C), and noticed the beam persisted without attenuation for several days after the Cs reservoir heater was turned completely off. The source also fully recovered after significant vacuum excursions observed on the RGA.

Fig. 7 shows the extracted H^- beam current versus applied RF power with and without Cs. Over the higher power range, we observe an average power efficiency of ~1 mA/kW, nearly double that of the original SNS ion source [4]. Some earlier-reported power efficiencies of the SNS source were overstated due to a recently discovered and corrected error found in the control system. The discontinuity observed in Fig. 7 likely corresponds to the activation of a secondary RF-plasma mode. The next step will be to isolate the Cs transfer line from excessive plasma heating and conduct tests at 60 Hz, the required SNS repetition rate. We expect that the significantly larger total beam current made available from this source configuration will contain a much greater portion of the beam (~40mA) within the acceptance of the SNS accelerator. Measurements to prove this will be performed as soon as a suitable emittance detector is made operational.

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