H^- SURFACE CONVERTER SOURCE DEVELOPMENT AT LOS ALAMOS*

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Abstract

Production of H^- ions by the surface conversion process is being pursued at the Los Alamos Neutron Science Center (LANSCE) as part of an upgrade project to provide higher currents and enhanced flexibility for injecting a 800 MeV H^- beam into the proton storage ring (PSR). An eventual goal of 40-mA H^- current at 80 keV beam energy with 0.13 πmm-mrad (1rms normalized) emittance at 12% duty factor (120 Hz, 1ms) is desired. To attain this goal, two types of surface converter sources are being investigated in which H^- ions are extracted either radially or axially through a line-cusp magnetic field. The radial source produces 18 mA H^- in a 28-day run cycle for LANSCE production while the axial source has been developed to the desired 40 mA current. However, an emittance growth of factor 2-3 accompanied the increased axial source current. The axial source development program includes electron suppression, increased beam current, and 80-keV beam emittance measurements. The current understanding of the emittance growth mechanism will be discussed.

INTRODUCTION

The LANSCE upgrade project[1] goal is to attain 200 μA average current at a spallation neutron source target. The PSR[2] compresses an approximate 1ms H^- source macropulse to 250 ns. PSR beam instabilities[3] have been observed in the beam compression process. Both the higher current LANSCE facility request and PSR tuning flexibility would benefit from a higher current H^- source. For these reasons a higher current H^- surface converter source was developed for LANSCE in collaboration with the Lawrence Berkeley National Lab (LBNL). This collaboration produced a six-filament axial source[4] which produced the required 40-mA H^- current, and a higher-perveance accel column.[5] A factor 2-3 emittance growth, however, was discovered while testing the 80-keV axial source at LANSCE.[6] The surface conversion process has been used at LANSCE to provide reliable H^- beam operations since 1985.[7] The present LANSCE production source produces 18-mA H^-, at 12 % duty factor (120 Hz, 1ms), 80-keV beam energy, and 28 day lifetime.

EXPERIMENTAL RESULTS

An ion source test stand (ISTS), which has the same functionality as the 80-keV LANSCE production injector, has been built at Los Alamos.[8] Measurements reported here on the axial source were carried out on the ISTS. Figure 1 shows a PBGUNS[9] scale drawing of the prototype axial H^- source electrodes used in the LANSCE testing. The primary H^- production mechanism is the formation of H^- ions on the converter surface that are self-extracted by the -250 to -300V converter voltage. The electron suppressor, composed of electric and magnetic fields, is located in the repeller electrode. The emission aperture is 2.3 cm downstream from the repeller. For results reported here the emission aperture had radii = R_{em} = 0.5 and 0.8cm. Different magnetic field configurations for the repeller, including line cusp, solenoid ring, and undulator (opposing dipole), have been investigated to optimize the 80 keV e/H- ratios. The measured e/H^- ratios are shown in Fig. 2 as a function of the repeller electrode voltage. These measurements were made for an H^- beam current, I_b, equal to 33-mA extracted from the source with R_{em} = 0.8cm. The electron to H^- ratios are calculated by the formula e/H^- = $(I_{reg} – I_b)/I_b$ where I_{reg} equals the total pulsed current delivered by the 80-kV regulator circuit.[10] At repeller voltage of +10 V, the e/H^- = 1.1, 2.3, and 4 for the undulator, ring cusp, and line cusp magnets, respectively. Many measurements were made on the e/H^-

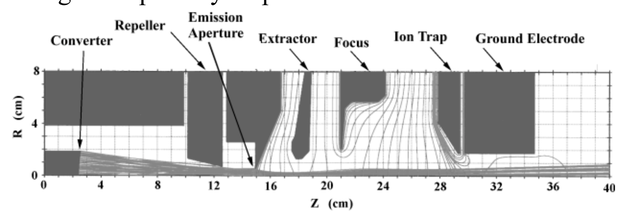

Fig. 1. PBGUNS trajectory simulations for the prototype axial H^- source used in these measurements.

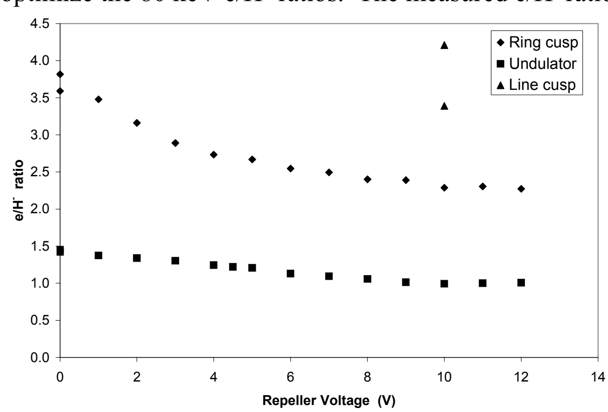

Fig. 2. The measured e/H^- ratios for three different repeller magnet configurations.

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ratio for the line cusp, and the two points for the line cusp in Fig. 2 are representative of the spread for different source tunes. There is a clear preference for the undulator magnetic field for electron suppression.

Figure 3 shows the measured H^- current as a function of discharge power, P_d, for the source equipped with R_{em} = 0.8cm. P_d is the product of the discharge voltage and current. The H^- current is measured in a current transformer after the beam passes through a low-energy beam transport solenoid magnet, thus nearly eliminating the remaining co-extracted electron current. The discharge voltage varies from –140 to –190V in these measurements. The H^- current, considering the data scatter, has a weak dependence on the magnetic filter arrangement in the repeller electrode. The 40-mA current level is reached most efficiently (less discharge power) in the order of line cusp, undulator, and then the ring cusp magnets. Another feature seen in Fig. 3 is an approximate dependence of extracted H^- current on the square root of the discharge power. For comparison to the data an empirical curve showing $I_b(mA) = 10(\sqrt{P_d}(kW))$ is shown.

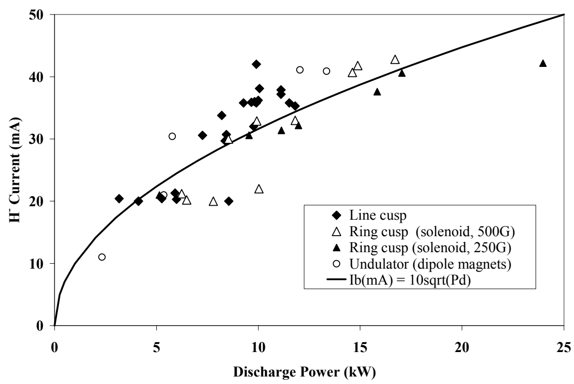

Figure 3. Measured H^- current as a function of the discharge power. R_{em} = 0.8cm in these measurements.

The I_b vs P_d data for the axial source with the R_{em} = 0.5cm emission aperture is shown in Fig. 4. Here the filled triangle and open circle symbols are H^- currents measured at two different H_2 gas flows with the converter voltage varying between –230 and –270V. The undulator repeller magnet configuration is used in acquiring the Fig. 4 data. An approximate square root dependence of I_b on P_d is again observed. The empirical square root dependence is shown by the equation $I_b(mA) = 3.47\sqrt{P_d}(kW)$. The filled square and open diamond symbols show that significant H^- currents are extracted for the measured P_d when the external converter power supply is switched off. This result is suggestive that production mechanisms other than surface production at the converter are significant in the axial source and apparently increase with discharge power.

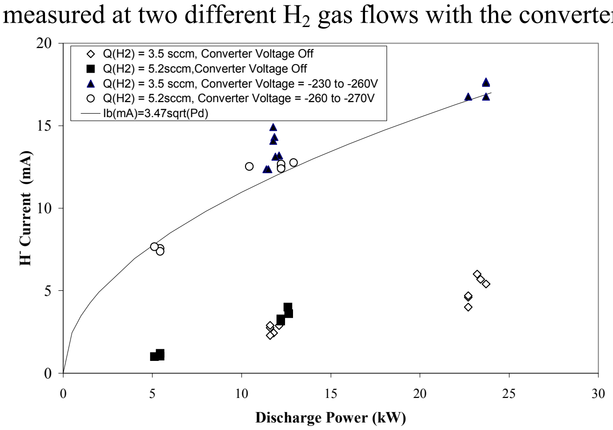

Figure 4. Plot of the measured H^- currents vs discharge power for R_{em} = 0.5cm.

A selection of emittance measurements for the 80-keV beams with R_{em} = 0.5 and 0.8cm are shown in Fig. 5.

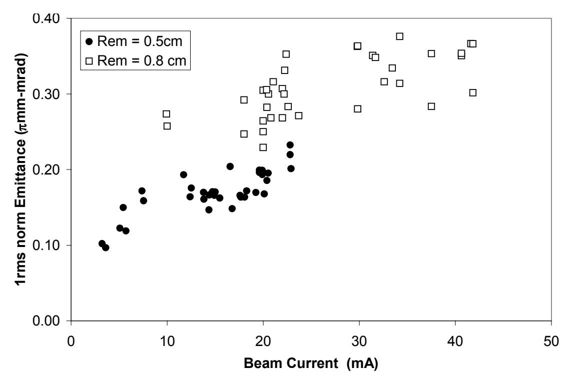

Figure 5. Summary of normalized emittances measured on the axial surface converter H^- source.

The total lab emittance was extracted from the phase-space scans with the area calculated for 98% of the beam, $\varepsilon_{tot}(98\%)$. These total lab emittances are then converted in low ion energy limit to 1rms normalized ($\varepsilon_{1rms,n}$) by the equation $\varepsilon_{1rms,n} = \beta^*\varepsilon_{tot}(98\%)/7$, where β is the relativistic velocity factor for 80-keV H^- ions and the factor 7 is applied to convert the 98% beam fraction to 1rms beam fraction.[6] On this $1\varepsilon_{rms,n}$ emittance scale, the present LANSCE accelerator emittance request is in the range of 0.13 – 0.15 (πmm-mrad). Measurements made by LANSCE operations team[11] confirm that the 750 keV transport would have to be rebuilt to accommodate the larger emittances associated with the R_{em} = 0.5cm and 0.8cm apertures reported in Fig. 5.

DISCUSSION

The admittance limit for the R_{em} = 0.5cm and 0.8cm emission apertures are calculated to be 0.10 and 0.14 (πmm-mrad) ($1\varepsilon_{rms,n}$). These admittances are calculated on the basis of uniform H^- beam illumination[12] of the repeller and emission apertures from the converter surface at converter voltages (typically –250 to -300V). Such a diagram, constructed at the emission aperture, is shown in Fig. 6 for the axial source geometry shown in Fig. 2 where R_{em} = 0.5cm. The discrete points contained within the admittance diagram are phase-space predictions derived from the PBGUNS code.[9] These admittances are a reasonable expectation of the beam emittance, and is found to be true (cf measured emittances at low beam currents reported in Fig. 5). A proposed interpretation for the emittance growth observed between the admittance limits and the higher-current emittances observed in Fig. 5 is that two beams corresponding to directed H^- ion energies characteristic of converter (≈300eV) and plasma sheath (≈12eV) energies appear simultaneously at the plasma meniscus. Such a mixed species beam has previously been observed in magnetron H^- sources[13] which have similar geometric construction to the present H^- surface converter source.

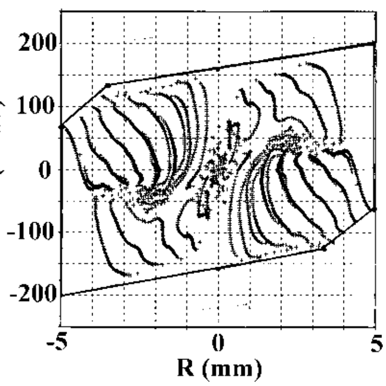

Fig. 6. Admittance diagram for the surface converter source geometry shown in Fig. 2.

Further evidence for a mixed species beam is shown in Fig. 4 where significant H^- currents are observed with the converter voltage turned off. A PBGUNS model was made for extraction of mixed species beam from a plasma. The $1\varepsilon_{rms,n}$ emittance results are shown in the ordinate of Fig. 7. The abscissa contains the percent of 12eV species compared to 300eV species. The prediction

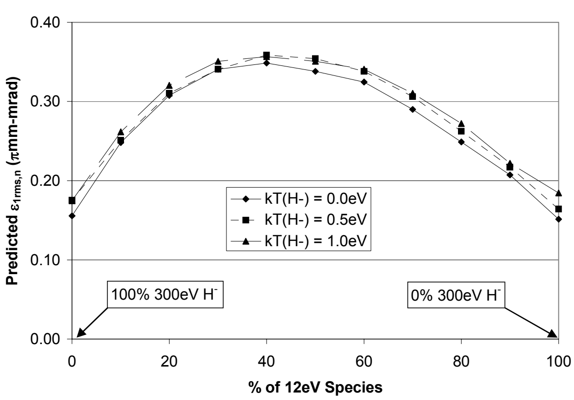

Fig. 7. PBGUNS model for emittance predictions of extraction of mixed-energy H^- from a plasma source.

at the limit of pure surface converter (left) is in agreement with admittance expectations. However, predictions are that admixture of 10% of a 12eV component give a rapid rise in predicted emittance. The mechanism for emittance growth proposed here is one of mismatch[14], not of increased H^- ion temperature. Figure 7 shows predictions for the three ion temperatures of 0.0, 0.5, and 1.0 eV in a Maxwellian model, and their influence on the predicted emittance is small compared to the mismatch mechanism. The emittance growth model predictions are in the 2 – 2.5 range, about the same as the measured emittance growths shown in Fig. 5. Thus, a reasonable physical picture for the experimentally observed emittance growths is the simultaneous extraction of 250 to 300 eV surface converter produced and order 12 eV volume or anode produced ions. The results from Fig. 4 show evidence that a two-component beam increases as discharge power increases, just as emittance (Fig. 5) increases with beam current, or equivalently P_d.

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