

A PROPOSED HELICON DRIVER FOR THE SNS ION SOURCE

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Abstract

The Spallation Neutron Source* (SNS) employs an RF-driven, multi-cusp, H⁻ ion source, which utilizes a helical antenna to inductively couple power into the source plasma. To date, the source has been successfully utilized in the commissioning of the SNS accelerator producing 10-40 mA of H⁻ with duty-factors of ~0.1%. In the coming years, the SNS ion source will be required to inject ~60 mA into the linac with a duty-factor of 7%. This may require extraction of currents of up to ~100 mA from the ion source depending on source emittance. To date, the SNS source has only delivered sustained currents of ~30 mA at this duty factor. We are therefore exploring the possibility of meeting these requirements by combining a helicon hydrogen plasma generator recently developed in the Fusion Energy Division (FED) at ORNL with the existing SNS H⁻ ion source. Both these systems have been highly optimized and reflect the current state of the art in high-density hydrogen plasma production and high-brightness H⁻ generation. The helicon plasma generator has demonstrated the capability of producing H₂ plasma densities up to an order of magnitude greater than can be achieved in the current SNS source. This report describes the technique we will employ to couple these systems as well as our plans to realize a helicon driver for the SNS ion source.

INTRODUCTION

The Spallation Neutron Source (SNS) is a large multinational user facility dedicated to the study of the dynamics and structure of materials by neutron scattering and is currently commencing operations at Oak Ridge National Laboratory (ORNL) [1]. The SNS Power Upgrade Project will roughly double the scientific capability of the facility at a fraction of the initial cost and have enormous impact in many areas of neutron, material and biological sciences [2]. The SNS power upgrade will require H⁻ currents at the ion source of 70–100 mA, depending on emittance (normalized RMS emittance = 0.20-0.35 π mm mrad.), with a ~7% duty factor. Currently, no ion source in routine operation at existing facilities can simultaneously meet these requirements for sustained run-periods [3]. We are, therefore, developing several different source types [4] as well as designing optimized versions of the original SNS ion source [5]. Each of the schemes under consideration involves considerable pulsed-power transfer to the plasma: 50-100

kW. So far the best results show that the original ion source can only produce sustained H⁻ currents of ~30 mA.

In this work, we propose a plan to boost beam current to required levels by retrofitting a proven, well characterized, low-power (4-6 kW), helicon hydrogen plasma generator, recently developed by the ORNL-FED, to the original SNS ion source. The original SNS ion source was developed at Berkeley National Laboratory (LBNL) and is shown schematically in Fig. 1 and described in detail in Ref. 6. Briefly, up to 80 kW of RF power excites a helical antenna, which produces magnetically confined H₂ plasma. A transverse magnetic field, produced by the filter magnets, prevents fast electrons from entering the extraction region of the source, which could destroy the fragile H⁻ ions prior to extraction. The Cs collar, shown in the figure, provides additional shielding from the primary plasma as well as serving as a source of Cs coating nearby surfaces.

Fig. 2 shows a plot of the extracted H⁻ beam current (after cesiation) versus plasma density sampled near the center of the plasma chamber using an RF-compensated Langmuir probe and optical spectrography. The plot was made by varying the RF power from 10-40 kW. These data suggest that if the density at this location can be increased by a factor of ~3, H⁻ beam currents would be sufficient to meet the SNS power upgrade current requirement, providing the scaling holds.

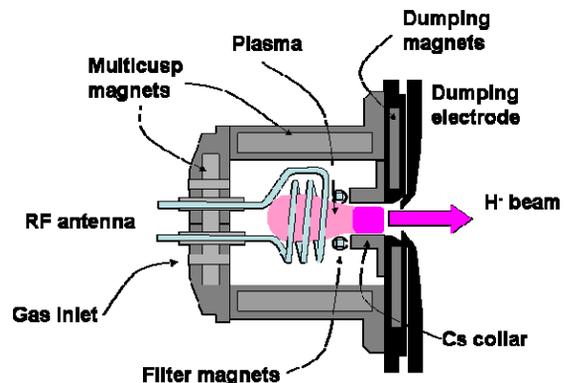


Figure 1: Schematic diagram of the original SNS ion source.

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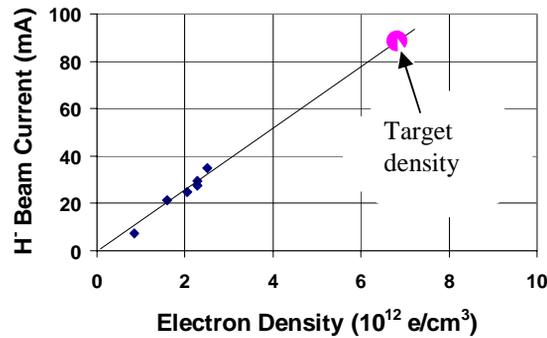


Figure 2: Plot of plasma density measurements versus extracted H^- beam current.

THE HELICON PLASMA GENERATOR

Fig. 3 shows a photograph of the helicon plasma generator developed by the ORNL-FED Plasma Technology and Applications Group for space propulsion studies. The apparatus consists of two magnetic solenoids: the primary one producing a long uniform B-field and a smaller mirror coil located at the end of the primary solenoid. These solenoids surround a long quartz plasma chamber ($\phi=5\text{cm}$, $l=100\text{cm}$). RF power is coupled into the plasma through a helicon-type antenna located near the center of the long solenoid. Plasma density achieves a maximum near the center of the mirror solenoid. The group was the first to achieve hydrogen plasma densities above $\sim 10^{12}$ ions/ cm^3 with a helicon generator, reaching maximum densities of $2.5 \times 10^{13} \text{ cm}^3$ in a 5 cm diameter source with ~ 4.5 kW of input power, and pulse lengths up to several seconds (limited only by available cooling) [7]. The central electron temperature of ~ 6 eV is similar to that measured in the SNS ion source. Fig. 4 shows a microwave interferometer measurement of the plasma density achieved with 6 kW of RF power at 21 MHz.

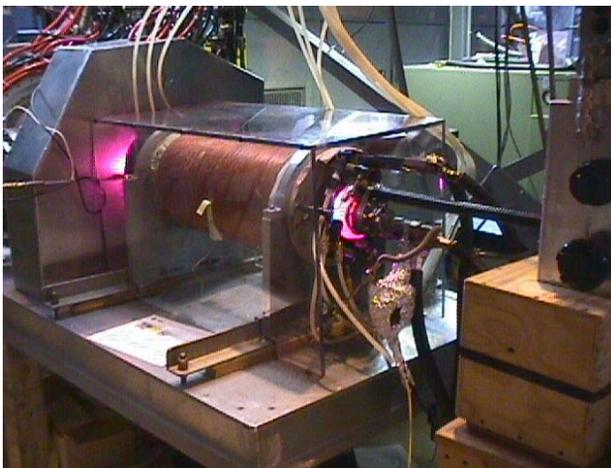


Figure 3: The ORNL-FED Helicon test stand.

THE INTEGRATED HELICON-SNS ION SOURCE

Fig. 5 shows the integrated helicon – SNS ion source. The source body is the same as the one employed in the high-power source described in Ref. 8. The original SNS outlet aperture, magnetic filter and dumping fields and Cs collar mount directly to the source body, preserving their optimized configuration. When energized, both solenoid coils shown in the figure can create a nearly identical axial field profile to the one used to create high density plasma in earlier helicon work. Fig. 6 shows the resulting axial and transverse magnetic field profiles. The primary solenoid from the helicon plasma generator is utilized, while a smaller mirror solenoid is custom fabricated to be inserted into the ion source plasma chamber.

The steel yoke shown in Fig. 5 has been added to rapidly attenuate the B-field in the extraction region of the source to prevent interference with the magnetic field of the filter magnets, as well as prevent beam emittance growth due to B-field in the extracted beam. The blue and green curves also plotted in Fig. 6 show the transverse B-field profile with (green) and without (blue) the solenoid magnets at a location 1 cm off-axis. We see from these calculations that the addition of the helicon solenoids has very little effect on the magnetic field distribution of the extraction region of the source where the H^- is formed. It is therefore unlikely that disproportionate amounts of harmful fast electrons will enter this region, impeding H^- formation and extraction as plasma density is increased. Furthermore, since both volume and surface H^- formation mechanisms should increase at least linearly with plasma density, we expect the observed H^- scaling with plasma density will continue at least into the mid 10^{12} ions/ cm^3 range, provided plasma thermal loads are managed and extraction conditions are adjusted to accommodate the increased plasma density.

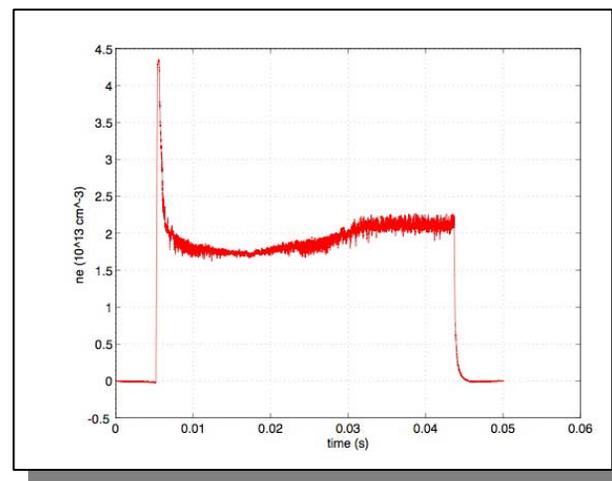


Figure 4: Interferometric measurement of H_2 plasma density in helicon mirror region for a 40 ms, 6 kW RF-pulse.

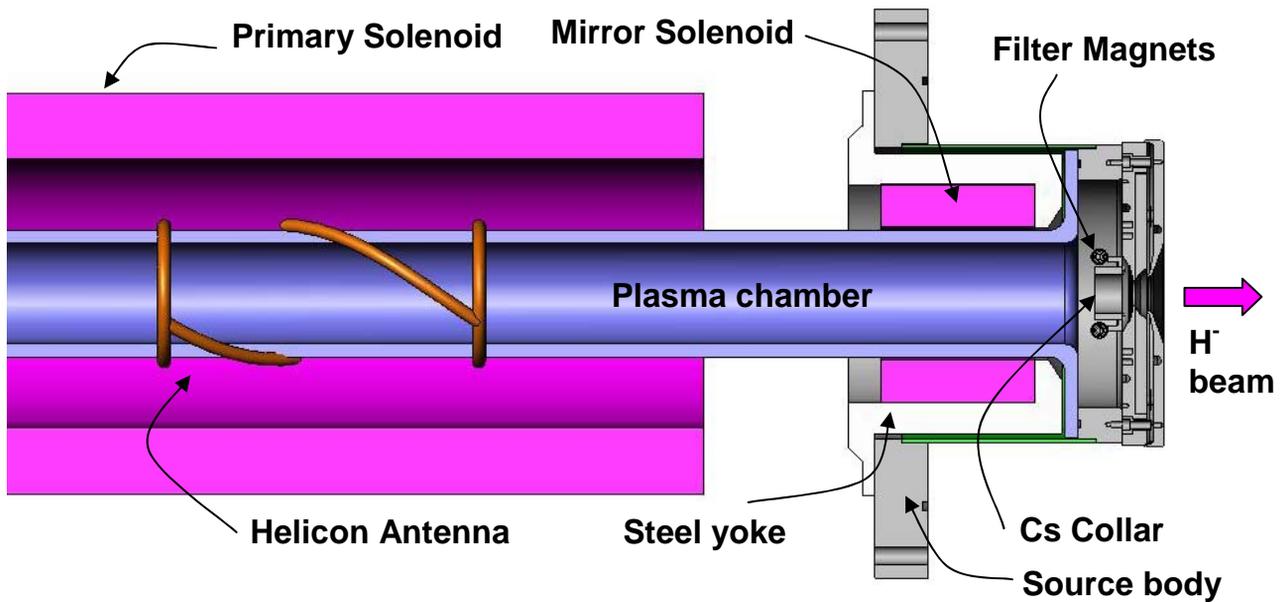


Figure 5: The proposed integrated SNS – helicon ion source.

THE RESEARCH PLAN

The research plan is to (i) Modify the existing helicon plasma generator by adding the compact mirror coil, 1010 steel shaping piece, and filter magnets shown in Fig. 5. The device will then be operated with the goal of maximizing plasma density and minimizing electron temperatures in the region directly downstream of the filter magnets. Langmuir probes calibrated against a 70 GHz microwave interferometer will be employed in the FED facility. (ii) The helicon device will then be moved to the SNS ion source test stand, where beam extraction and emittance measurements will be performed at very low duty-factor. (iii) If the earlier stages are successful, a prototype high duty-factor source will be designed, constructed, and tested with additional cooling and fully optimized integration of the helicon, negative ion production, and acceleration regions.

CONCLUSION

We have shown that two highly optimized systems can be integrated in a manner which is unlikely to significantly degrade the performance of either. Both axial (helicon) and transverse (H^- source) magnetic field distributions can be successfully combined with minimal perturbation. The helicon plasma generator has been proven to function without issue at plasma densities of $2.5 \times 10^{13} \text{ e/cm}^3$. H^- scaling suggests that only densities of $\sim 7 \times 10^{12} \text{ e/cm}^3$ are needed to meet the SNS power upgrade requirement, which provides a considerable margin of safety. The low power requirement of helicons' 4-6 kW versus 50-100kW for conventional H^- ion sources and the external antenna format is likely to result in significantly extended lifetimes and enable heretofore unprecedented pulse lengths and increased duty-factors.

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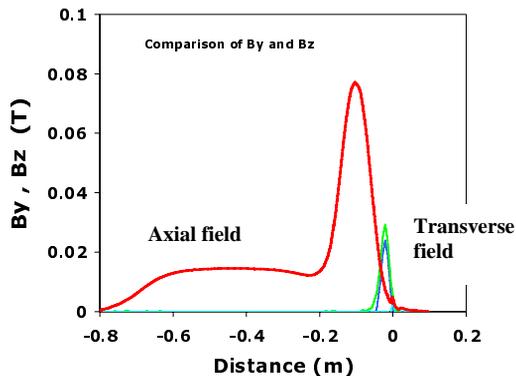


Figure 6: ANSYS calculations of the axial and transverse magnetic fields in the proposed integrated SNS – Helicon ion source.