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Progress in the Computer Simulation of LANSCE's Production H^- Ion Source*

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Abstract

1D and 2D particle-in-cell (PIC) codes have been developed to study the negative hydrogen (H^-) ion sources used at the LANSCE accelerator. These ion sources operate through a surface conversion process, generating an H^- beam at a negatively biased, cesiated electrode immersed in a hydrogen plasma. Preliminary results indicate that some modifications of the original design may improve the ion source efficiency. The simulations indicate that the propagating beam is highly divergent due to a larger than expected sheath region around the cesiated electrode and due to the defocusing edge fields at the converter.

1. Introduction

Production of H^- ions at the Los Alamos Neutron Science Center (LANSCE) has been carried out reliably by the same surface converter technology for the past two decades. Increased efficiency of these ion sources is an important problem given the significant economic benefits associated with higher H^- current outputs[1]. If the H^- current output is doubled (I_{H^-} ~ 40mA), the resulting decrease in the duty factor of the RF systems would allow a reduction in operation costs estimated at over US$3 M/yr. Figure 1 shows a schematic of the usual view regarding the beam generation and propagation through the plasma. The source operates by immersing a negatively biased (between -250 and -300V) "converter" electrode in a hydrogen plasma. The electrode surface is cesiated thus favoring the formation of H^- ions through the processes of reflection and sputtering of the impinging positive ions. It was thought that the beam angle of convergence was mostly determined by the radius of curvature of the converter surface and that given the smallness of the plasma-converter sheath region, all beam transport would occur in a neutralized state. The expected efficiency of the ion source would depend heavily on these assumptions, as the converging beam from the converter would need to get through a 1.7 cm diameter aperture 7cm away.

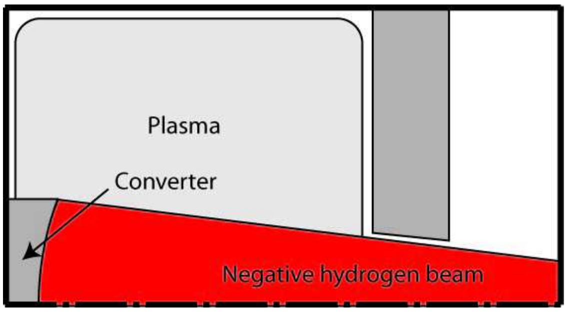

Figure 1. Usual view of the generation and propagation of the H^- beam within the ion source.

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2. Preliminary 1D Simulations.

A preliminary study was carried out with a one-dimensional PIC to explore the physics within the beam path. It was desired to assess the distribution of the longitudinal voltage drop in the beam and to observe if the converging beam could give rise to significant space-charge de-neutralization. The simplified model was done in a spherical geometry. It consisted of 2 concentric shells, with the radius of the outer one equal to the radius of curvature of the converter electrode. The gap between the shells was set equal to the distance between the converter and the exit aperture (~ 7 cm). The gap was filled with a constant H^+ particle density. The inner sphere acted as a perfectly absorbing boundary, while the outer shell produced H^- and e$^-$ whenever it was struck by an incoming H^+. The conversion efficiencies for H^- and e$^-$ were $\gamma_H^- = 0.7$ and $\gamma_e^- = 1$ respectively for these tests. When an H^+ was absorbed by either boundary, it was regenerated within the volume with a simulated e^- impact ionization. The results obtained for a low plasma density of $3 \cdot 10^{14}$m^{-3} are shown in Figure 2.

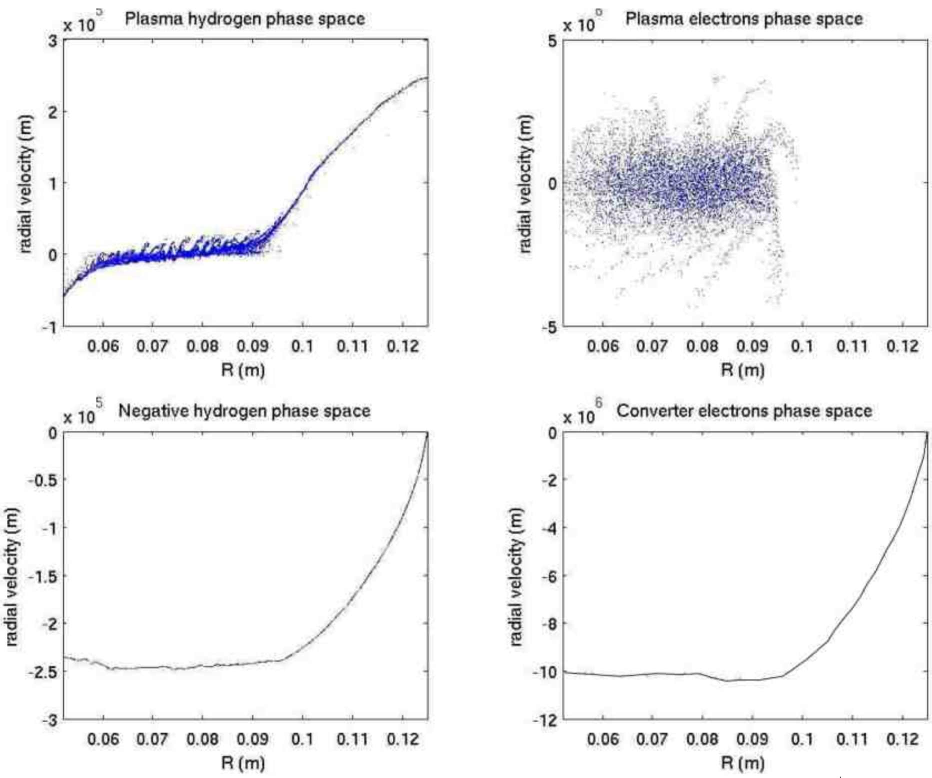


Figure 2. Phase space of the particle species modelled with the 1D code. $n_H^+ = 3.10^{14}m^{-3}$.

The $n_H^+ \sim 3 \cdot 10^{14}$m^{-3} choice for these simulations was because at higher n_H^+, the H^- and e^- currents from the outer shell would cause significant heating of the plasma e^-. This occurred because the model did not include dissipative processes (i.e.: collisions with neutral particles). Nevertheless, the 1D simulations indicated the presence of a large sheath region surrounding the converter. This would be a region of un-neutralized transport where the H$^-$ beam would be expected to diverge. While the expectation was that this sheath would shrink as n_H^+ increased, it was clear that unless the sheath collapsed to zero, the ballistic focusing model for this ion source would not hold.

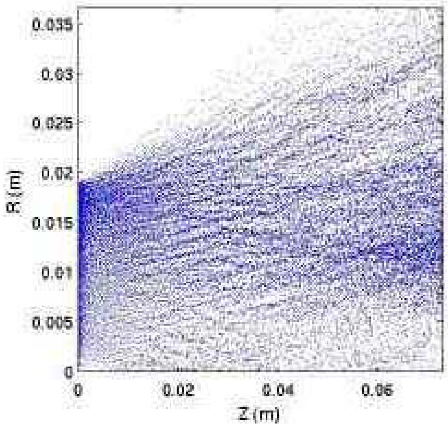
Another important feature that is observed with the 1D simulations was the existence of induced waves in the plasma species due to the interaction with the beam particles. Of particular importance is the coupling between the H^- beam and the plasma ion acoustic waves, as this is the suggested mechanism to explain oscillations of similar magnitude (~1 MHz) that are sometimes observed at the LANSCE accelerator. These oscillations are not entirely reproducible in the experiments so it is believed that the overall mechanisms that cause the oscillations are more complex than the physics currently incorporated in the simulations. Analytical models derived in these investigations suggest that these waves may be quenched if sufficient particle collisionality is included[2]. It is noteworthy that whenever the beam oscillations are observed in the experiments it is the increase in H_2 gas flow what quenches the oscillations.

2. Two-dimensional simulations.

A 2D axisymmetric code is under development. This code also applied the first principles approach used in the simpler 1D case, preserving the full electron effects. The independent physics parameters to the code are: temperatures of the individual species, positive ion particle density, converter particle efficiencies for H^- and e^-, converter voltage, exit aperture voltage (the repeller electrode), and the distance along the boundary over which the converter voltage decays to zero. To maintain a rectangular solution region, the converter was simulated as a straight line on which the emitted particles would receive an initial average converging direction proportional to the distance to the axis of symmetry. This would simulate the converter radius of curvature. Other numerical parameters like the number of cells in each direction, total number of simulation particles and timestep are chosen to preserve adequate statistics and resolution of the plasma debye length, as well as to avoid aliasing phenomena or other numerical instabilities.

The potential field solver was chosen to permit reasonably fast solutions at realistic conditions expected to exist in the ion source (H^+ particle density ~ $10^{17}m^{-3}$). Therefore, to solve Poisson's equation a split solver was implemented, using a Fourier method to solve for the fields along the direction of propagation of the beam, and a tridiagonal matrix solver along the transverse direction. In its current form, the code performs approximately $8 \cdot 10^5$ particle pushes per second, with plenty of room for performance improvement. The absorbing and emitting properties of the boundaries were implemented analogously to the 1D code discussed above. An example of the results from the 2D code is shown in Figure 3.

Figure 3 shows the results obtained for a simulation at $n_H^+ = 3 \cdot 10^{16}m^{-3}$. While not yet at the high plasma density desired for the final analyses, it became clear that the beam generation conditions favored a divergent beam that for the most part would not make its way out of the ion source. The initial divergence is affected by the fringe fields at the converter outer radius. Other simulations using an extended converter electrode that would smooth out these fields reduced the divergence appreciably, but still far from providing a desirable beam envelope.



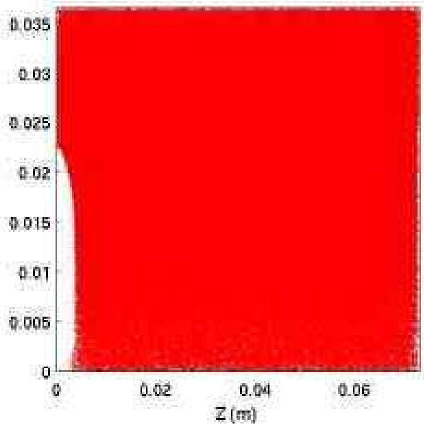


Figure 3. RZ simulation of the emitted H- (left) and the distribution of plasma e^- around the -300V biased converter electrode. H^+ particle density = $3 \cdot 10^{16} m^{-3}$. Simulation time: $3 \cdot 10^{-7} s$.

3. Conclusions

The preliminary simulations shown have provided useful insights into the beam propagation dynamics within the ion source. These insights point at very specific directions of work with high promise of increasing the ion source efficiency and current output. Work is underway to include elements of internal geometry inside the solution region that would provide an engineering prescription to modify the ion source converter. The result would be a plasma-simulator/gun-code tailored to the required analyses for LANSCE’s ion source work. For example, an extension of the converter electrode as a focusing element providing an initial converging impulse to the beam would likely emerge as a good approach. Further work is planned as well for increasing the speed of the axisymmetric R-Z code and for incorporating more detailed physics. For example the incorporation of external magnetic fields (the cusp fields) and the corresponding implementation of a magnetic particle push. Lastly, the incorporation of Monte-Carlo routines to account for beam destruction and other collision processes of interest is a goal in this effort. This theoretical work is developed in parallel with an ongoing experimental program[3] in which the ideas generated through this effort can be tested.

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