# BEAM SIMULATIONS FOR THE H-INJECTOR UPGRADE AT LANSCE

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## Abstract

An upgrade program is being carried out at Los Alamos to increase the peak beam current from the present H⁻ injector to provide 200 μA average current for the proton storage ring at LANSCE. In order to meet this objective, the injector must provide at least 30% more current than presently available. More optimal operation, however, requires a factor of two higher peak current in order to reduce circulating losses in the ring. At these higher currents, a lower beam emittance is needed to limit beam losses in the linac. Beam simulations have been carried out to model the operation, of the present injector and to determine what changes will be required to operate with these higher beam currents. A collaboration with the Lawrence Berkeley National Laboratory (LBNL) is now in progress to modify our present converter ion source to produce 40-mA peak of H⁻ beam current with reduced beam emittance. Beam simulations show that a new 80-kV accelerating column will be needed to accelerate and transport these higher current beams with acceptable beam size and divergence. Experimental results for the initial phase of this program are presented together with a comparison to these beam simulations.

## 1 INTRODUCTION

The upgraded H⁻ injector must produce high-duty factor, low-emittance H⁻ beams with good reliability and availability in order to meet the operational requirements at the Los Alamos Neutron Science Center (LANSCE). The present surface converter ion source provides the reliability and availability needed [1]. Previous work at LBNL with a similar barium converter source [2,3] has demonstrated that a factor of two increase in converter efficiency can be obtained for this type of ion source by filtering the primary plasma. Experiments carried out with a cesiated molybdenum converter [4] have demonstrated that the required 40 mA of beam current can be produced.

The design of a new accelerating column was carried out by first benchmarking the ray-tracing code PBGUNS against the operation of the present accelerating column. Then this code was used to determine what changes were needed to design a column capable of accelerating higher beam currents with the required exit beam parameters.

## 2 LANL ION SOURCE

The configuration of the present LANL converter ion source together with the 80-kV accelerating column is shown in Fig. 1.
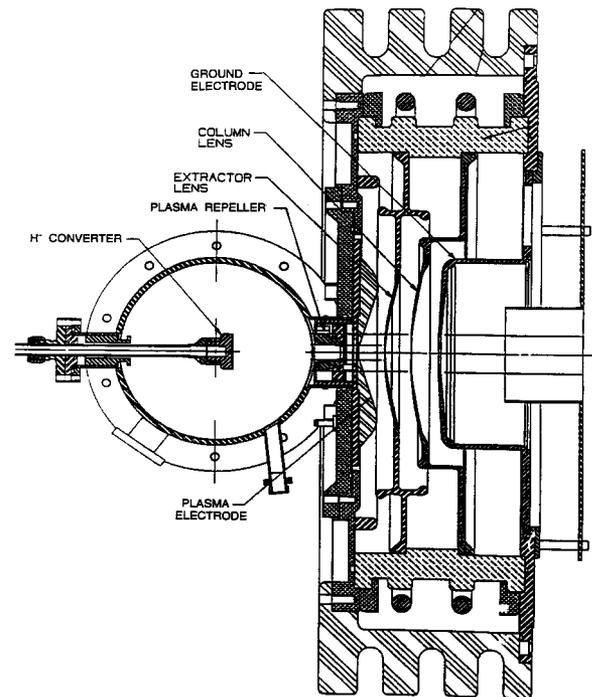


Figure 1: Layout of the LANL converter ion source with the present accelerating column.

The H⁻ ions are sputtered from the surface of a cesiated molybdenum converter electrode and are subsequently accelerated to several hundred electron volts by the cathode sheath formed at the converter surface by the applied bias voltage. These ions are self-focused by the spherical surface of the converter and form a converging beam that exits the source at the plasma electrode. The ion beam is collimated both by the 1.0-cm diam. plasma electrode aperture and by the plasma repeller assembly within the source itself. The emittance of the beam extracted from the ion source is determined by the geometrical admittance. For low converter voltages, the beam fills the phase space available and the beam emittance is equal to the ion source admittance. The extraction electrode is located 2.5 cm from the plasma electrode and has a 2.2-cm diam. aperture. The extraction voltage required for our present 16-mA production beam is only 12 kV. This is

a consequence of the high energy (250 eV) of the converter beam and of the relatively low plasma density at the plasma electrode. The difference between the extraction voltage and the total column voltage is applied across two high-voltage gaps in the column with the intermediate voltage being variable. For the present operation, this voltage difference is split equally between these two high-voltage gaps.

## 3 BEAM SIMULATIONS

The ray-tracing code PBGUNS Version 3.20 [5] has been used to model the production of the H- beam in the ion source and the subsequent acceleration in the 80-kV accelerating column. This code computes beam trajectories starting at the converter surface and propagates the beam through the ion source plasma and then subsequently accelerates the beam through the 80-kV accelerating column into the low-energy beam transport (LEBT) line. Emittance plots can be produced at four positions along the beam line, and the evolution of the beam phase space can be followed through the system as the ion source and accelerating column parameters are varied.

## 4 TEST STAND PROGRAM

To carry out the development of a new ion source, the LANSCE ion source test stand (ISTS) was rebuilt to have the same configuration as the injector in the accelerator. Thus, it now provides a means for testing ion source improvements and modifications in an off-line environment [6]. A spare converter ion source was mounted on the ISTS, and beam tests were carried out which demonstrated that the operation of the ion source on the test stand was the same as that on the injector.

Although the PBGUNS code had been benchmarked against experiments for positive ion sources, there has not yet been a similar validation for the negative ion sputter sources that we are using [7]. We decided, therefore, to carry out an experimental program to compare the simulation predictions to the emittance data taken with our present ion source. A series of emittance scans were taken at the first emittance station (EM-1) in which the ion source parameters were held constant and the extraction voltage was varied from 8 kV to 15 kV. A

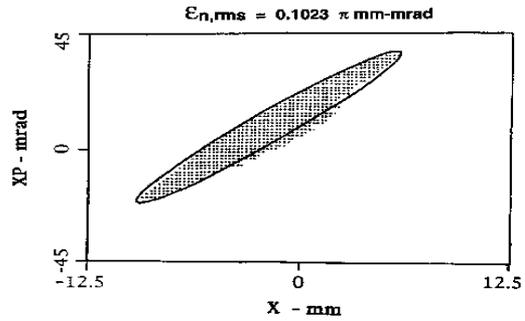typical emittance scan for the 12-kV case is shown in Fig 2.



Figure 2: Horizontal emittance scan of a 16-mA H⁻ beam at the column exit with 12-kV extraction voltage.

Simulations were then run for all the extraction voltages with the ion source parameters fixed at the production values. The calculated phase-space distribution for the 12-kV extraction voltage case is shown in Fig. 3.
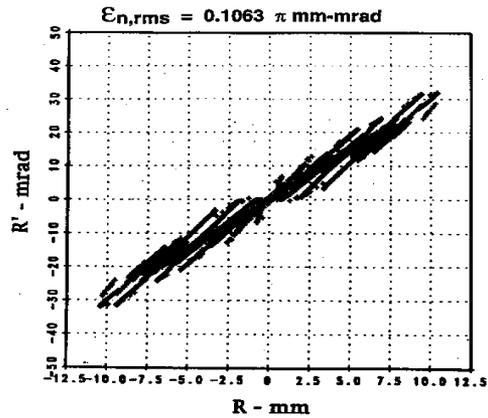


Figure 3: Calculated emittance distribution of a16-mA H⁻ beam at the column exit for 12-kV extraction voltage.

The experimental data observed at EM-1 and the corresponding PBGUNS simulations are compared in Table I.

Both the ray-tracing code and the emittance analysis code

Table 1: Comparison of Emittance Data and PBGUNS Simulations

| kV | $\pi$ mm-mrad | | | cm | | mrad | |
| Extraction Voltage | Normalized rms Emittance | | Mismatch Factor | Beam Size | | Beam Divergence | |
| | EM-1 | PBGUNS | | EM-1 | PBGUNS | EM-1 | PBGUNS |
| 8.0 | 0.0984 | 0.1096 | 1.53 | 0.880 | 0.879 | 29.19 | 18.41 |
| 9.0 | 0.1096 | 0.1065 | 1.53 | 0.893 | 0.924 | 31.34 | 21.88 |
| 10.0 | 0.1003 | 0.1071 | 1.30 | 0.853 | 0.948 | 30.68 | 24.85 |
| 11.0 | 0.1032 | 0.1040 | 1.23 | 0.848 | 0.941 | 31.86 | 25.79 |
| 12.0 | 0.1023 | 0.1063 | 1.20 | 0.803 | 0.939 | 31.08 | 27.44 |
| 13.0 | 0.1018 | 0.1044 | 1.26 | 0.763 | 0.913 | 30.78 | 27.21 |
| 14.0 | 0.0100 | 0.1036 | 1.27 | 0.714 | 0.891 | 29.97 | 27.44 |
| 15.0 | 0.0972 | 0.1028 | 1.32 | 0.672 | 0.856 | 29.86 | 27.57 |

carry out a second moments analysis to determine the rms emittance of the beam. We see that for the rms emittance the experimental data and beam simulations agree to within a few percent. We note that for the converter source being modeled, the beam size and divergence values given by PBGUNS on the emittance plots are closely approximated by the 2rms values calculated by this code, i.e., by the beam parameters of a 4rms beam. We have, therefore, chosen to compare the beam parameters for the experimental beams with the 4rms beam parameters calculated by PBGUNS. We see that the beam sizes for the observed EM-1 beams are typically 10% smaller than the calculated 2rms beam size and that the observed beam divergences at EM-1 are approximately 15% larger than the 2rms divergence values. Thus, while the beam code calculates the phase space area correctly, there are still systematic differences between the measured and simulated beam size and divergence which probably arise from errors in the location of beam transport elements or errors in the assumed space-charge neutralization model. Work is in progress to resolve these discrepancies.

## 5 HIGH-VOLTAGE COLUMN SIMULATIONS

Having established that the LANSCE H⁻ injector beam can be modeled with the PBGUNS code, we carried out simulations for the higher beam currents. We first determined the performance of the present injector systems as we increased the extracted beam current. We increased the extraction voltage to keep the beam perveance constant in the extraction gap as the extracted current was increased. Thus, as the beam current was increased from 16 mA to 40 mA, the extraction voltage was varied from 12 kV to 22 kV. The variation of beam emittance and beam sizes at several locations in the beam line are shown in Fig. 4.
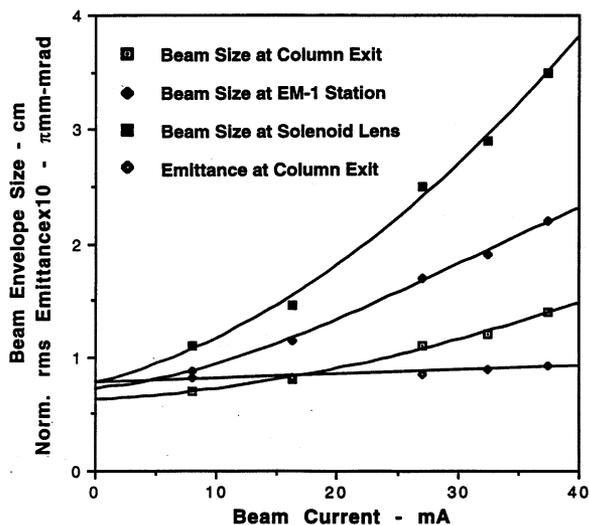
Figure 4: Beam emittance at the column exit and beam sizes in the LEBT as a function of extracted current.

We see that the emittance of the beam at the column exit remains essentially constant over this range of currents for the perveance matching employed in the extractor gap. The beam size in the beam line increases continuously with increasing current and exceeds the aberration limit in the solenoid lens (half the bore aperture) for 27 mA and fills the bore aperture for currents approaching 40 mA. Thus, the present injector can be used for beam currents up to 27 mA without emittance degradation, but a new accelerating column with stronger focusing will be required for beam currents at the 40 mA level.

Several accelerating column designs have been studied using this simulation code. The beam profiles for a high gradient tetrode column with a decel ion trap and for the present accelerating column are presented in Fig. 5. The beam envelope sizes in the LEBT for the tetrode design with 40 mA are essentially the same as those with the present column for 16-mA beams.
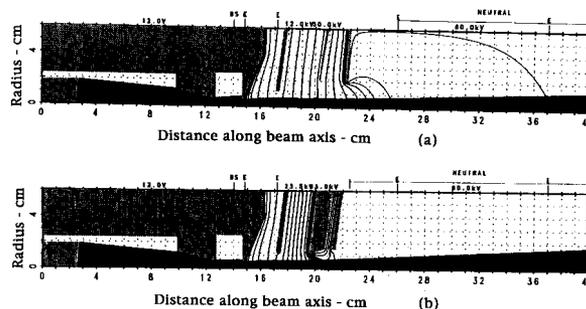
Figure 5: Trajectories and equipotentials for the 16-mA production beam with the present accelerating column (a) and for a 40-mA beam with a high gradient tetrode column (b).

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