STATUS OF THE H^- INJECTOR DEVELOPMENT PROGRAM AT LANSCE*[*]

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Abstract

The H^- injector at Los Alamos National Laboratory (LANL) is being upgraded to provide a 12% duty-factor, 40-mA, 80-kev H^- beams, which will enable 200-µA operation of the Los Alamos Neutron Scattering Center (LANSCE) proton storage ring (PSR). An improved version of the LANSCE operational surface-conversion ion source and a new accelerating column have been developed in collaboration with the Lawrence Berkeley National Laboratory (LBNL) for this application [1]. We report here the results of the initial tests at LANL on a proof-of-principle (POP) ion source built at LBNL and on modeling studies. The POP ion source has been operated at the 40-mA design beam current, and the beam emittance of the 80-keV extracted beam has been measured both at the exit of the accelerating column and in the 80-keV low-energy beam transport (LEBT) line. Significant, current-dependent, emittance growth was observed in the LEBT. Experimental investigations of this growth are described.

1. INTRODUCTION

A goal of the Short Pulse Spallation Source (SPSS) Enhancement Project [1] at LANL is to upgrade the existing facilities at LANSCE to reliably produce 200 µA for the Manuel Lujan Neutron Scattering Center target. To achieve this SPSS goal, a significant increase in beam current from the H^- injector is required. Higher peak current will reduce the fill time of PSR and reduce the stored-beam losses, and higher peak current allows an increased gap in the chopped beam, which could improve beam stability at high currents. A minimum of 20 mA is essential; a beam current of 40 mA is the desired goal. Our present H^- injector produces 16-17 mA of beam with a normalized beam emittance equal to 1.0 π mm-mrad for 95% of the beam. A reduction in beam emittance is also required; smaller emittance should reduce beam losses in the linac. A normalized beam emittance of 95% of the beam should be less than 0.8 π mm mrad, whereas 0.4 is our desired goal. To limit the demand on resources, we will continue using the present 80-keV LEBT and plan to achieve the injector improvements via source and column upgrades.

2. THE EXPERIMENTAL SETUP

2.1 The Ion Source Test Stand (ISTS)

The ISTS was built to develop the necessary injector improvements without interfering with LANSCE operations. We designed the ISTS to duplicate the H^- 80-keV beam transport inside the LANSCE 750-kV injector dome. The ISTS has additional emittance diagnostics to better characterize the beam behavior. They are located at end of column (EM01) and at the location of the entrance to the 670-kV accelerating column (EM03). The EM02 diagnostic is located between the two solenoids as in the LANSCE injector. Reference [2] give a detailed description of the ISTS. Figure 1 shows an 80-kV dome LEBT schematic.

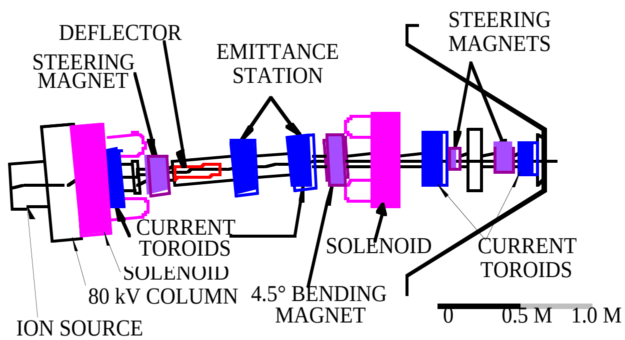

Figure 1 Line Drawing of the Dome LEBT

2.2 New 80-keV Column Design

The present 80-kV column has shortcomings when operated with high currents in our present LEBT. During normal operations we limit emittance growth in the column, typically, by perveance matching in the column. To prevent the formation of aberrations in the first LEBT solenoid, we must produce a beam at the column exit with relatively small beam size and with small divergence so not to fill the aperture of the first solenoid. Using the present column, we cannot simultaneously maintain a perveance-matched beam and control the beam size in the LEBT. This inability becomes unacceptable at high-beam currents. The new-column design addresses the above problems. It uses an asymmetric Einsel lens and provides perveance matching and independent beam focussing for a range of high currents. Simulations show that this column can produce sufficiently small beam sizes at high currents. In addition, the new column includes an ion trap to stop back-streaming positive ions, thereby, reducing their damage to the ion source and enhancing the beam neutralization in the downstream LEBT. Figure 2 shows the new column design. The new column has been

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installed but not tested. All following results were made with the operations-type column.

3. EXPERIMENTAL RESULTS

3.1 Operations Source

As reported earlier [2,3] concerning the operations source, we found that the beam at EM02 had the same emittance as measured in the LANSCE injector. Using the additional emittance station, EM01, we also observed that the beam had the emittance equal to the expected source admittance.

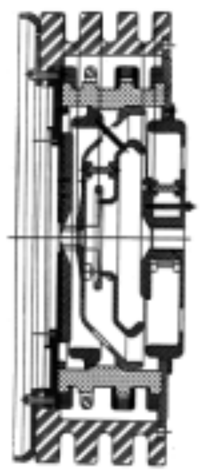


Figure 2 Line drawing of the new 80-keV column design

Because the emittance at EM02 is significantly larger than EM01, all the observed emittance growth occurs in the first 104 cm of the LEBT.

3.2 POP Source

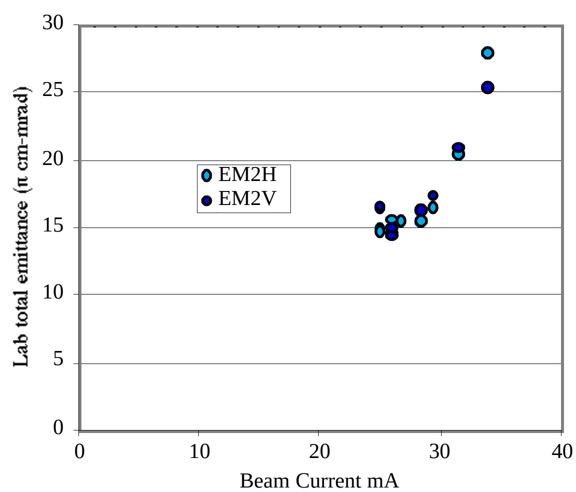
Initially the POP source produced significantly less beam than observed at LBNL. Simulations of the source and column showed that significant beam current loss occurred on the 1-cm plasma aperture. We enlarged this aperture to 1.6 cm, obtained 40 mA of H^- current, and confirmed the previous LBNL measurement [4]. With the 1.6-cm aperture the beam current increased linearly with arc current as it reached 40 mA; however the LANSCE operations source saturated at 28 mA. An interesting but unexplained observation is that for a given arc current the operations-source beam current increased by only 10% when the aperture was enlarged; however, the POP-source current increased by a factor of two. Nonetheless, increasing the plasma aperture did increase the maximum current from the operation source.

3.3 Emittance measurements and growth

We were unable to obtain a complete set of EM01 measurement at the exit of the column. However, two EM01 measurements showed that the normalized rms emittance was 0.014 and 0.018 π cm-mrad with the POP and operations sources respectively. These emittance areas, with the enlarged plasma aperture, are again similar to the admittance (0.014 π cm-mrad) of the source and predictions of PBGUNS [5]. The POP source supplied 24.5 mA, and the operations source supplied 15 mA during these measurements.

Using the 1.6-cm plasma electrode aperture, we continued to observe significant growth between column exit and EM02. Using the operations source we observed that the normalized total emittance at EM02 increased from 0.25 to 0.31 π cm-mrad emittance (a 25 % increase) as the beam current increased from 8 to 24 mA. Using the POP source we measured a normalized total emittance increase from 0.20 to 0.29 π cm-mrad (a 45% increase) as the current increased from 24 to 34 mA. Above 28 mA of beam current the EM02 emittance increases rapidly with increasing beam current, but below 28 mA the rate of increase is significantly less. See figure 4. PBGUNS simulations show that for beam currents above 28 mA, the beam size in the first solenoid becomes sufficiently large so that the solenoid will begin causing significant aberrations to the beam. We observe that the rms emittance, which is determined using a moments analysis, increases even more rapidly with beam current than the total emittance. This result supports our conclusion that part of the increasing emittance growth is caused by beam aberrations from the solenoid. It should be noted that when both sources were producing the same amount of current, 24 mA, the beam emittance with the POP sources was 33% smaller than that with the operations source.

Figure 3. Horizontal and vertical emittance at EM02 with the 1.6 cm plasma electrode aperture.



As we increased the beam current from the sources, we did not obtain a complete set of EM01 measurements to compare with all the EM02 measurements. However, where the comparison can be made and when the beam emittance should not be affected by solenoid aberrations, the emittance growth between EM01 and EM02 is greater than a factor of two. At higher beam currents where solenoid aberrations are also important, the emittance growth is significantly greater. To explore this emittance growth, we modeled the beam dynamics between EM01 and EM02 using the codes SCHAR [6] and SOLEN [7] and used three different initial beam distributions, the 4-volume, the KV and the Gaussian distributions. The initial beam distribution was constrained to have the Courant-Snyder [8] parameters and rms emittance of the measured beam. Figure 4 shows the simulated dependence of EM02 emittance on beam current and beam distribution. Of the three distributions, only the Gaussian distributions produced the observed emittance

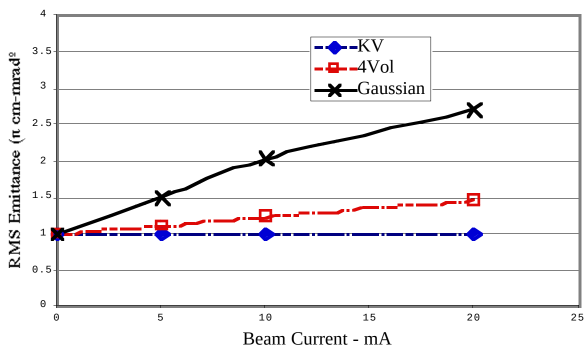


Figure 4. Rms Emittance at EM02 as a function of effective beam current for various assumed beam distribution

growth. Our beams appear to have a Gaussian distribution because we found that the total emittance (E) has the dependence

$$E(F) = K \times \ln(1/1-F))$$

where F is the beam fraction contained within the area E and K is equal to twice the rms emittance value. Such dependence is indicative of a Gaussian distribution [9]. See figure 5.

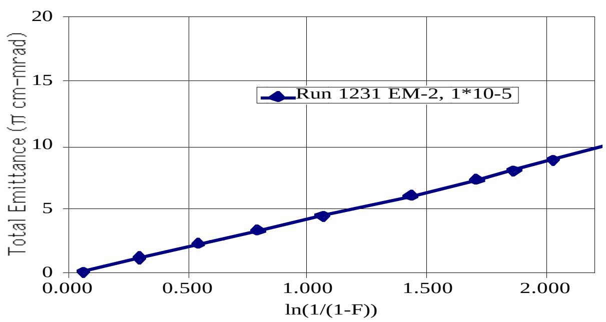


Figure 5. Total Emittance versus fraction of beam enclosed

We suggest that emittance growth was the result of beam space charge effects due to an incompletely neutralized beam. To test this hypothesis we added argon gas to the LEBT and measured the EM02 emittance versus gas pressure in the LEBT. Because we were seeking a qualitative result, we did not attempt to uniformly distribute the argon in the LEBT, but only added gas at one point. We observed 15% decrease in emittance that varied approximately linearly with gas pressure.

4. CONCLUSIONS AND FUTURE PLANS

We confirmed that the POP source can meet the SPSS beam-current goal; the POP produced more beam than the operations source. We observed that the emittance at EM01 was smaller using the POP source compared to using the operations source at the same beam current. Significant emittance growth occurs between the column exit and the mid-point of the 80-keV LEBT; the growth is at least a factor of two. Initial measurements indicate that the emittance growth was in part due to space charge effects that can be reduced with the addition of a neutralizing gas. Beam-dynamics simulations indicated that beams with Gaussian distributions could exhibit the kind of emittance growths that we observe. Furthermore, the measured emittance dependence on beam fraction is consistent with a Gaussian distribution.

Because the present beam emittance at the mid-point of the LEBT does not meet the SPSS requirements we must develop methods to reduce the emittance growth in the LEBT. To support our development, we will examine the following topics: Can we limit the emittance growth between EM01 and EM02 by more uniformly adding neutralizing gases in the LEBT? Does the new column perform as designed? Does emittance growth occur between EM02 and EM03? What are the beam production characteristics of the final version of the LBNL source and do they meet the SPSS requirements?

5. REFERENCES

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