# DEVELOPMENT AND TEST RESULTS OF THE LOW-ENERGY DEMONSTRATION ACCELERATOR (LEDA) PROTON INJECTOR ON A 1.25 MeV cw RADIO FREQUENCY QUADRUPOLE*

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*Abstract*

The low-energy demonstration accelerator (LEDA) 75-keV proton injector is being developed for tests of high-current (100-mA) cw linacs. The injector comprises a microwave proton source and a space-charge neutralized magnetic low-energy beam-transport system (LEBT). The LEDA injector has been configured to provide flexible 50-keV beam matching into a cw 1.25-MeV radio-frequency quadrupole (RFQ) brought from Chalk River Laboratories (CRL). The LEBT has two solenoid focus magnets separated by 117 cm. Between the solenoids are two steering magnets and diagnostic stations for measuring the beam current, profile, and position. The ion-source extraction system was modified to a 50-keV triode to test the injector/RFQ system. Beam-matching tests showed that injector-RFQ transmission is 90% for 50-mA RFQ current. At the RFQ design current of 75 mA the beam transmission decreased to 80 - 85%. Optimized injector tuning led to 100-mA beam accelerated through the RFQ.

## 1 INTRODUCTION

In 1993, a 1.25-MeV cw RFQ designed for 75-mA beam current operation[1] was brought to Los Alamos from CRL for continuation of proton beam testing[2]. The final operation at CRL led to 55-mA current accelerated by the RFQ[3] using a direct-injection single-solenoid focus LEBT with no beam-steering capability[4]. Problems encountered using this LEBT for RFQ matching were discussed, but no further injector technology development was possible at CRL.

A more advanced proton injector is under development at Los Alamos for the LEDA project. This effort culminated in demonstration of a 75-keV, 130-mA proton injector[5] appropriate for the 6.7-MeV LEDA RFQ. After completion of the 75-keV injector demonstrations, the LEDA injector was modified to operate at 50-keV proton beam energy to make integration tests with the 1.25-MeV cw RFQ. This injector includes two solenoid focusing magnets, and two pairs of steering magnets for increased beam steering and matching flexibility to a RFQ. Modification of the ion extraction system from 75 to 50 keV led to a 50-keV injector whose operating parameters are shown in Table 1.

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Table 1. 50-keV LEDA proton injector operation.

| Parameter | Design | Measured |
|---|---|---|
| Beam current (mA) | 100 | 150, max. |
| Proton fraction (%) | 90 | 95, max. |
| Beam energy (keV) | 50 | 50 |
| 2.45 GHz power (W) | 600-800 | 1000-1500 |
| Axial magnetic field (G) | 875 | 875-960 |
| Beam duty factor (%) | 100 | 100 |
| Emission radius (mm) | 3.4 | 3.4 |
| Extraction gap (mm) | 8.1 | 8.1 |
| Inj. $E_{rms,n}$ ($\pi$mm-mrad) | 0.20 | 0.15 |
| RFQ output current (mA) | 75 | 100, max |
| RFQ acceptance ($\pi$mm-mrad) | 0.5 | |

## 2 50-KEV INJECTOR DEVELOPMENT

The first 50-keV LEDA injector beam tests were completed on the prototype injector shown in a line drawing in Fig. 3 of ref.[5]. A microwave proton source[6] is used to generate a dense plasma with proton fractions in the 90 - 95% range[5,7]. Fifty-keV ion beam extraction was first attempted with the tetrode (four-element) extractor (Fig. 2 of ref.[5]) where the full acceleration voltage is held across a single gap between the first (plasma) and second (extraction) electrodes. The third electrode (electron trap) is held at -1500 V while the fourth electrode is at ground potential to terminate the electric fields from electrode 3. The beam-current requirement is transmission of 100-mA current through the LEBT solenoids. Only 50% beam transmission was observed with the tetrode, and the poor transmission was traced to higher beam divergence at 50 keV. The increased divergence arises from an increase of beam perveance, $P_b$, of the $I_b$=90-mA, $V_b$=50000-V injector $P_{50keV}$= $42.9X10^6(I_b(A)/V_b^{3/2})$=0.34 μP compared to the 130-mA, 75-keV injector where $P_{75keV}$=0.27 μP. A series of PBGUNS beam simulations comparing a triode (three-electrode accel-decel system) with the tetrode extractor is shown in Fig. 1, where the calculated maximum angle is plotted vs. $P_b$ at fixed 50-keV beam energy. Four calculations for both extractors were done using a 9.2 mm extraction gap with a $r_{em}$ = 3.4 mm emission aperture radius. They are connected by solid lines. The letter “D” appended to a point indicates the extracted beam is divergent and the letter “C” indicates a convergent beam. The reduced triode divergence arises from an approximate 1-cm reduction of unneutralized space-charge beam transport achieved by the more compact triode extractor. The beam transmission through the LEBT solenoids on the prototype injector increases to > 90% when the triode

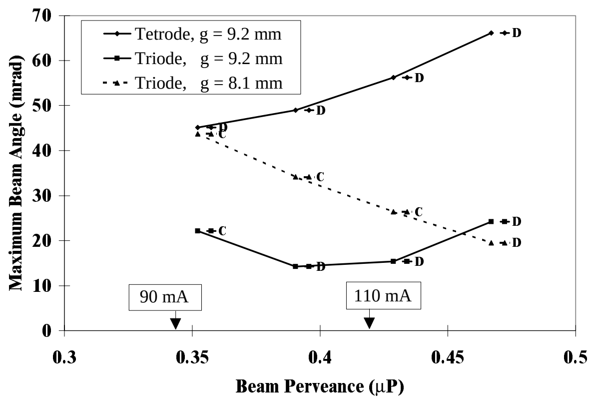


Figure 1. Maximum angle predictions from the PBGUNS code for the 50-keV ion extraction systems.

produced 90-mA beam with an extraction gap g=9.2 mm. The first focus solenoid is located 79 cm from the ion extractor, thus a beam with 45 mrad divergence (the 50-keV tetrode extractor, cf Fig. 1) at extraction position will grow to 3.5 cm radius - too large for good transmission through the 10 cm (diameter) aperture LEBT solenoids.

Baseline injector beam phase-space data using the triode extractor were accumulated on the prototype injector for use in follow-on LEBT/RFQ matching calculations[8]. These data were accumulated in dc mode, and were measured a distance of 213 cm from the ion extractor. The rms normalized emittance, $E_{rms,n}$ is 0.15 ($\pi$mm-mrad), and nearly constant over the $P_b$ range. The data were projected back to the ion source by use of the TRACE code[9] using four times rms laboratory emittance ($4E_{rms}$). The Courant-Snyder $\alpha,\beta$ parameters extracted at the ion source are plotted vs proton beam perveance in Figs. 2 (A) and (B) respectively. The TRACE calculations used an effective transport current of $0.02I_b$ (1.8 mA) based on proton beam neutralization measurements[10]. Fig. 2(A) shows that this procedure leads to a convergent beam ($\alpha$>0), which agrees with the 90 mA (0.34 μP) PBGUNS triode calculation shown in Fig. 1. The average $\beta$ from Fig. 2 is 0.023 (cm/mrad) thus yielding $X_{max}$= $(\beta 4E_{rms})^{1/2}$ = 3.7 mm, which agrees adequately well with $r_{em}$ = 3.4-mm.

The triode ion source was installed on a 2.54-m long version of the LEDA injector LEBT attached to the 1.25-MeV RFQ. This injector is shown in Fig. 3, and has all the ion-optical transport features of the final 2.8-m proton injector[11]. During injector operation with the g = 9.2 mm triode, it became evident that injector currents greater

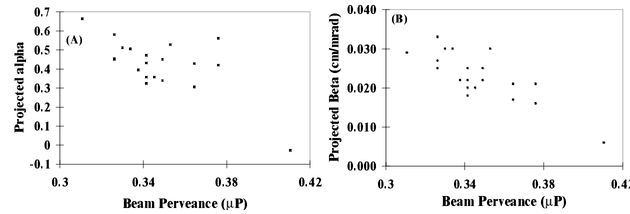


Figure 2. (A) Shows the baseline $\alpha$ and (B) the baseline $\beta$ parameters projected to the 50-keV triode extractor installed on the prototype injector. Calculations based on these measurements are used in the 1.25 MeV cw RFQ calculations.

than 90 - 100 mA could not be efficiently transported through the LEBT, and the 75-mA RFQ design current could not be reached. As currents increased above 90 mA in DC1 the beam-profile widths in video diagnostics 1 (VD1) became unacceptably large. This has two effects: the LEBT beam transmission decreases, and the non-interceptive DC2 current monitor becomes increasingly

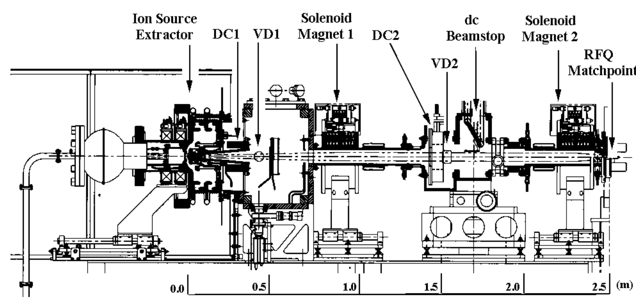


Figure 3. First version of the LEDA injector used for the 1.25 MeV cw RFQ tests.

susceptible to secondary electrons and beam plasma as the 50-keV beam approaches the vacuum wall. For these reasons, g was decreased from 9.2 to 8.1 mm. This step led to increased LEBT transmission (defined as DC2/DC1) for beam currents in the 110 - 115 mA range

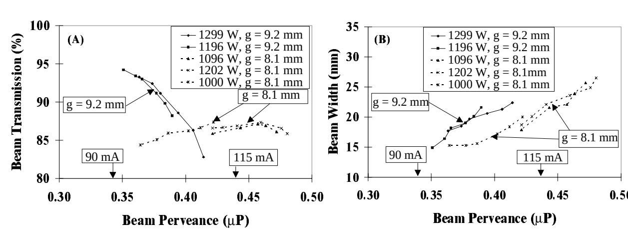


Figure 4. (A) Shows the increased beam transmission from DC1 (ion source) to DC2 (mid-LEBT), when the ion source extraction gap is decreased from 9.2 to 8.1 mm. (B) Shows the measured full-width, half maximum beam widths at VD1 for two data sets at g=8.1 and 9.2 mm extraction gaps. The lines are drawn to guide the eye.

(Fig 4(A)). The reduced extraction gap also decreased the beam size at VD1 for 110 - 115 mA beam currents (Fig. 4(B)). Plotting the beam transmissions and widths vs $P_b$ suggests these parameters follow unique curves defined by the extraction gap and $P_b$. The highest DC1 current recorded in Fig. 4 at 50 keV is 125 mA, giving $P_b$=0.477 μP. The improved injector optics with g=8.1 mm is also indicated in Fig. 1; the dashed curve shows that PBGUNS predicts a converging beam up to $P_b$=0.45 μP. The RFQ results reported below used g=8.1 mm.

## 3 TEST OF A 1.25 MeV cw RFQ

The basic 1.25-MeV RFQ design parameters are listed in ref. [1]. The primary diagnostic in the present measurement was to record the current transmitted through the RFQ with a third dc beam current monitor (DC3) located at the RFQ exit. See ref. [8] for a line drawing of the injector, RFQ, and CW beam dump installation. Other details on the operation of this RFQ at Los Alamos are given in ref. [12].

The RFQ transmission (%) is defined as 100(DC3/DC2). The present DC2 location tends to overestimate the RFQ input proton current which would indicate a lower-than-actual RFQ transmission. Secondary electron production and beam-plasma effects in the LEBT may also affect the accuracy of the DC2 measurement. Electrons flowing in the beam direction would produce a DC2 response lower than actual beam current, and would indicate a greater than actual RFQ transmission. An uncertainty of 5 mA in the DC2 current monitoring may be expected while the injector is operating at 75-mA RFQ design currents.

A check on the DC3 current monitor was made by doing calorimetry on the RFQ beam stop. At RFQ design current and energy there is 94-kW power in the RFQ beam. The agreement between the power measured by calorimetry and the power calculated from DC3 current assuming acceleration to full beam energy is good, varying from -6 to +2% depending on the RFQ exit quad excitation.

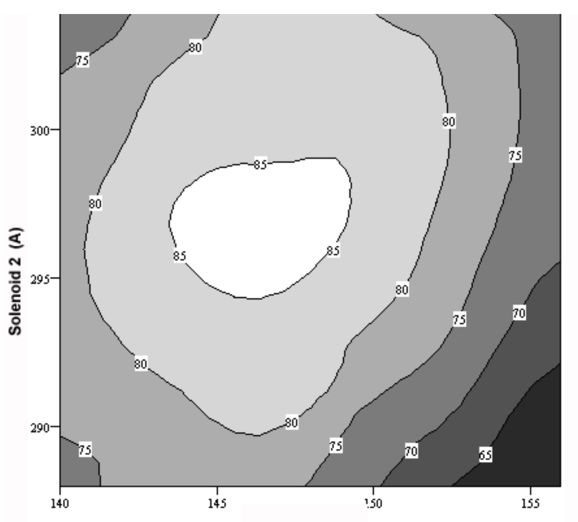

Figure 5. Contour plot of beam transmission through the 1.25 MeV RFQ as a function of the LEBT solenoid one and two currents. The RFQ is operating at 75-mA design output current for the 85% contour.

A systematic search of LEBT solenoids one and two led to the data shown in the contour plot of Fig. 5. The contour lines represent equal transmission in the solenoid tuning space. At the 75-mA RFQ design current, measured RFQ transmissions are 85%. On one occasion, while attempting to establish the maximum RFQ current, 100 mA was observed briefly in DC3. This high-current operation was limited by the injector's ability to deliver proton current to the RFQ matchpoint, and the limits of the RFQ rf power system [12]. DC1 current was 150 mA during the 100-mA RFQ current measurement. At 150-mA DC1 current, the beam is very large in the LEBT, and almost certainly the DC2 current monitor is adversely affected by secondary electron and beam plasma effects.

## REFERENCES

[1] B. G. Chidley, F. P. Adams, G. E. McMichael, T. Tran Ngoc, and T. S. Bhatia, "New Vanes for RFQ1", 1990 Linear Accelerator Conference Proc., LA-12004-C, 42.
[2] J. D. Schneider, et. al., "Installation of a CW Radiofrequency Quadrupole Accelerator at Los Alamos National Laboratory, Proc. of the 1994 Linear Accelerator Conf., (Aug., 1994, Tsukuba, Japan), 149.
[3] G. M. Arbique, et. al., "Beam Parameter Measurements on the CW RFQ1-1250 Accelerator", Proc. of the 1992 Linear Accelerator Conf., (Aug., 1992, Ottawa, Ontario, Canada), 55.
[4] G. M. Arbique, et. al., "High-Current Direct Injection to a cw RFQ Using an ECR Proton Source", Proc. of the 1992 Linear Accelerator Conference., (Aug., 1992, Ottawa, Ontario, Canada), 52.
[5] Joseph Sherman, et. al., Rev. Sci. Instrum. 69(2), 1003(1998).
[6] Terence Taylor and Jozef F. Mouris, Nucl. Instrum. Methods, Phys. Res. A 336, 1 (1993).
[7] Jim Kamperschroer, "Doppler-shift Proton Fraction Measurement on a CW Proton Injector", these Conference Proceedings.
[8] H. Vernon Smith, et. al., "Comparison of Beam Simulations with Measurements for a 1.25 MeV, CW RFQ", these Conference Proceedings.
[9] K. R. Crandall and D. P Rusthoi, Los Alamos National Lab Report LA-UR-90-4146 (1990).
[10] Robin Ferdinand, et. al., "Space-Charge Neutralization Measurement of a 75-keV, 130-mA Hydrogen-Ion Beam", to be published, Proc. of the 1997 Particle Accelerator Conf., (May, 1997, Vancouver, B.C., Canada).
[11] L. D. Hansborough, et. al., "Mechanical Engineering of a 75-keV Proton Injector for the Low-Energy Demonstration Accelerator", to be published, Proc. of the 1997 Particle Accelerator Conf., (May, 1997, Vancouver, B.C., Canada).
[12] G. O. Bolme, et. al., "Proton Beam Studies with a 1.25 MeV, cw Radio Frequency Quadrupole Linac", these Conference Proceedings.