HALF-POWER TEST OF A CW PROTON INJECTOR WITH A 1.25-MeV RFQ*

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Abstract

A 75-keV, 110-mA cw proton injector capable of pulsed operation has been developed for testing the LEDA 6.7-MeV cw radio frequency quadrupole (RFQ). Part of the preliminary development of this injector included operation of a 1.25-MeV cw RFQ at beam currents up to 100 mA. The 75-keV LEDA injector was modified to operate at 50 keV for these tests. We report here on the operational experience of the 1.25-MeV RFQ where 50-mA beam current was accelerated through the RFQ with 90% transmission. This half-power operation is of interest because (1) the injector beam current monitoring was more reliable, and (2) sufficient rf power was available to ensure the design cavity fields. These two features simplify the comparison of injector-RFQ performance with design codes. The information obtained from these studies will be applied to the 75-keV injector during the LEDA 6.7-MeV RFQ commissioning.

1 INTRODUCTION

Commissioning and startup of high-power cw RFQs[1] and cw accelerators[2] require initial operation at lower beam powers with pulsed and/or lower dc current beams. This lower-power operation allows insertion of diagnostic devices, which would otherwise be destroyed by the beam. Beam power can then be ramped up by guidance from design codes, previous experience, and careful attention to cw beam monitoring.

A 75-mA, 1.25-MeV cw RFQ[3] tested at Los Alamos[4] was commissioned by using a half-power injector beam operating in dc mode. In this paper we will discuss the injector design considerations for the half-power 1.25-MeV RFQ commissioning, and then will present the measured transmission results through the RFQ. This work confirms earlier design calculations[5] which predicted the 1.25 MeV RFQ transmission would be 90% at 50-mA accelerated RFQ current. A motivating factor for this work was injector development for the commissioning of a 6.7-MeV, 100-mA RFQ[6]. We refer to 50-mA operation as "half-power" because previous measurements[7,8] have obtained 100-mA beam current (25 mA greater than design) from the 1.25-MeV RFQ.

*Work supported by the US DOE, Defense Programs

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2 THE 50-KEV INJECTOR

A 75-keV injector based on a microwave proton source [9], has been designed, fabricated, and tested for the Low-Energy Demonstration Accelerator (LEDA) project. For the 50-keV tests the ion source beam extractor was modified from a tetrode to a triode system[8]. The two triode extraction geometries for the 50 and 100-mA 1.25 MeV RFQ operation are summarized in Table 1.

Table 1. Summary of the triode extraction systems used in the 1.25-MeV RFQ commissioning (50 mA) and highest power operation (100 mA).

1.25 MeV RFQ output current (mA)	50	100
Emission aperture radius (mm)	2.5	3.4
Extraction aperture radius (mm)	3.4	3.4
Extraction gap (mm)	9.3	8.1

Figure 1 shows the line drawing for the 50-keV injector used in these measurements. The ion source

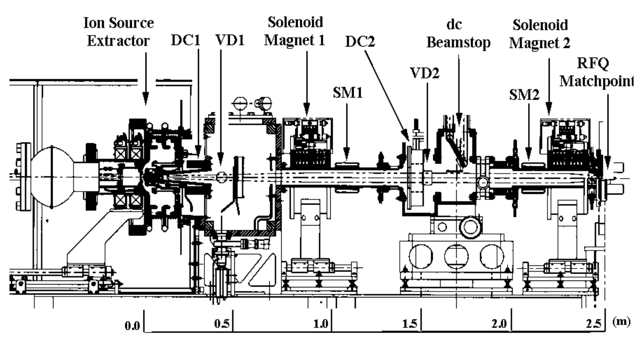

Figure 1. Line drawing of 50-keV injector used on the 1.25 MeV RFQ.

beam current, i_b, is measured in a dc current toroid labeled DC1 in Fig. 1. The source produced i_b = 58 mA accelerated through the 2.5-mm emission aperture radius (r_e) with 1270 W forward power at 2.45 GHz. This corresponds to an ion emission current density of j_i =

$i_b/(\pi r_e^2)$ = 295 mA/cm^2. The proton fraction was not measured while the injector was operating with the RFQ, but earlier proton fraction data acquired at 50 keV as function of the ion source microwave power are shown in Fig. 2. Proton fractions > 90% are observed for 900 W, and we therefore assume the ion source proton current is > 52 mA. At 900 W, within measurement accuracy of

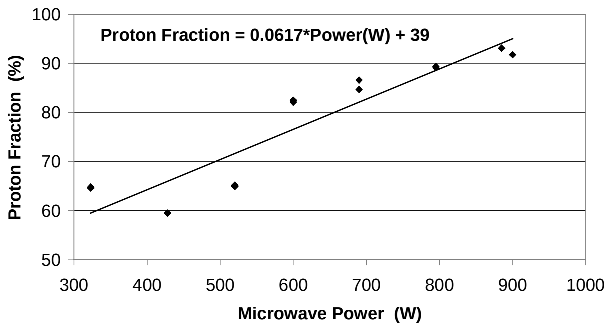

Figure 2. Proton fraction as a function of 2.45 GHz microwave power. The diamonds are measurements while the line is a linear least squares fit to the data.

1%, the remaining 10% of the beam is H_2^+.

Beam emittance was not measured for the 50-mA extraction system (cf Table 1). An estimate of the ion source beam emittance, however, may be made by use of the PBGUNS code[10]. This code includes a Maxwellian

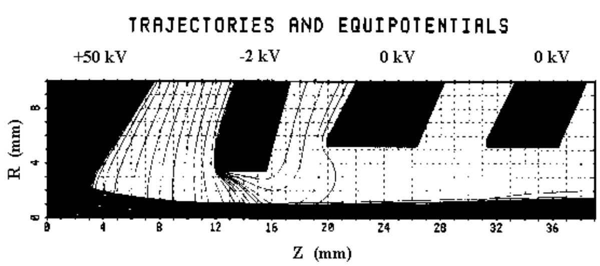

Figure 3. Simulation of the 50-keV beam using the PBGUNS code.

ion temperature, kT_i. Figure 3 shows the trajectory and equipotential plot for the 50-mA triode geometry summarized in Table 1 for kT_i = 1 eV. Predictions for the ion source rms normalized emittance, E_{rms}, are shown in Fig. 4 as function of kT_i. The PBGUNS code emittance prediction, shown as diamonds connected with solid line, is about 0.1 (πmm-mrad) for kT_i = 1 eV. This ion temperature may be a reasonable estimate for plasma ion temperatures in a microwave plasma source[11,12]. For comparison, the squares connected with the broken line are calculated from the temperature model formula, $E_{rms} = (r_e/2)(kT_i/mc^2)^{1/2}$ [13]. The code emittance prediction is greater than the temperature model because the PBGUNS code also includes ion-optical extraction aberrations and space-charge effects. The PBGUNS prediction is close to other ion-source emittance measurements[14].

3 RFQ BEAM MATCHING AT 50 MA

RFQ beam transmission measurements were made using the 2.5-mm emission aperture radius shown in Table 1. The LEBT solenoid magnets 1 and 2 were set at

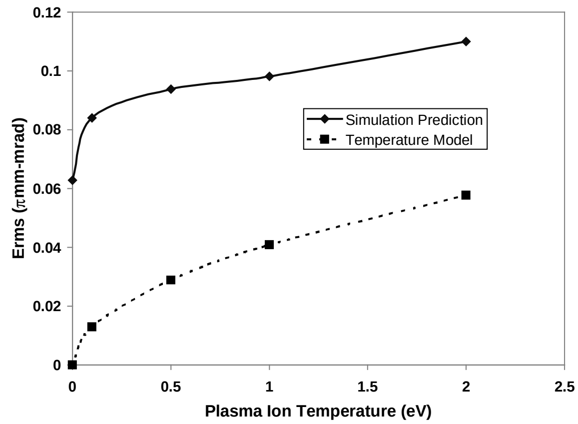

Figure 4. Prediction for the ion source normalized rms emittance from the PBGUNS code and the temperature model.

varying currents, and the transmission through the RFQ was measured. RFQ transmission is defined in per cent as 100(DC3/DC2). DC3 refers to a dc current toroid located at the exit of the RFQ[15]. Beam transmission measurements are shown as contours in Fig. 5 where the horizontal and vertical axes are the LEBT solenoid magnets 1 and 2 current excitation, respectively.

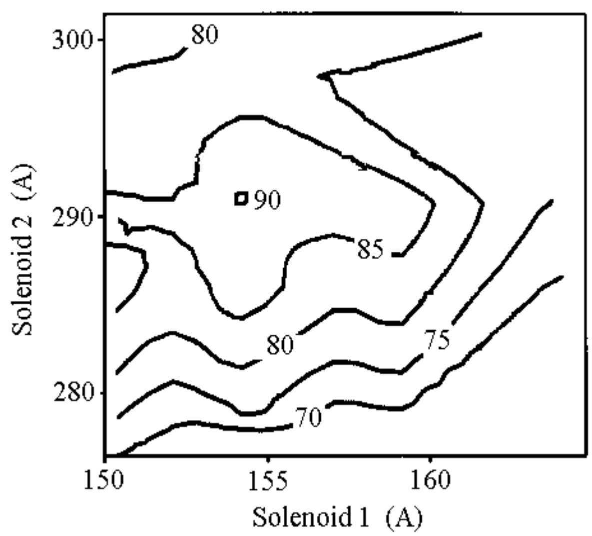

Figure 5. RFQ beam transmissions are plotted as contour labels.

The 90% contour corresponds to the RFQ half-power operation of 50 mA. Minimal steering magnet excitation (cf. Fig. 1, SM1, SM2) was required during these measurements.

First-order low-energy beam transport (LEBT) calculations using the TRACE code[16] were done using the PBGUNS predictions for the Courant-Snyder {α,β} parameters and the magnetic field strengths corresponding to the 90% transmission solenoid currents shown in Fig. 5. The TRACE beam envelopes for the {α,β} parameters corresponding to kT_i = 0 and 1 eV are shown in Fig. 6.

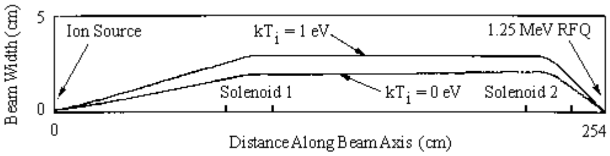

Figure 6. TRACE beam envelope calculations for the {α,β} parameters deduced from the kT_i = 0 and 1 eV PBGUNS simulations.

They give a good qualitative description of the RFQ-matched beam; a more quantitative description of this matching process requires use of a higher-order LEBT code [15]. The process of using the PBGUNS and TRACE codes together is a first-order method used for designing and commissioning the 50-keV injector on the1.25 MeV RFQ.

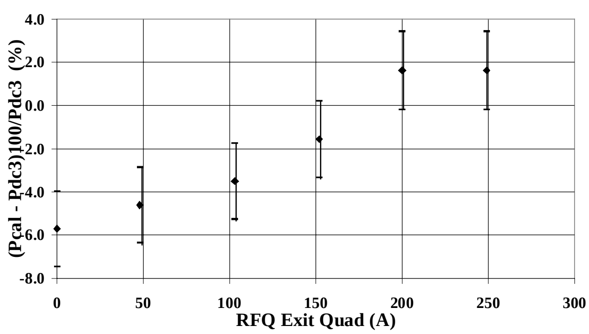

Figure 7. Calorimetric measurement beam power check on the DC3 beam current monitor.

A check was made on the RFQ output beam power and current monitor (DC3) by measuring the water temperature increase in the cw RFQ beam stop [17]. The difference of the measured calorimetric and beam power - based on the DC3 current measurement assuming acceleration to RFQ design energy – is chosen as a figure of merit. These difference data are shown in Fig. 7 plotted vs. the excitation of the RFQ exit quadrupole singlet. These measurements were made for an RFQ beam current of 74 mA with 1.3 l/s water flow. The equilibrium water temperature increase was 19°C. The error bars were calculated based on uncertainties in the temperature and water flow measurements. Some dependence is observed on the exit quadrupole excitation, but the calorimetry confirms the RFQ beam toroid current measurement.

4 ACKNOWLEDGMENTS

We thank Chalk River Laboratories for technical support in completing the work reported here.

References

[1] K. F. Johnson, et. al., “Commissioning of the Low-Energy Demonstration Accelerator (LEDA) Radiofrequency Quadrupole (RFQ)”, these conference proceedings.

[2] M. Olivo, E. Mariani, and J. Sherman, “The PSI 870 keV High-Intensity Cockcroft-Walton Preinjector”, Rev. Sci. Instrum. 63(4), (1992), 2714.

[3] B. G. Chidley, F. P. Adams, G. E. McMichael, T. Tran Ngoc, and T. S. Bhatia, “New Vanes for RFQ1”, Proceedings of the 1990 Linear Accelerator Conference, Los Alamos Report LA-12004-C, (Sept. 1990), 42.

[4] J. D. Schneider, J. Bolme, V. Brown, M. Milder, G. Neuschaefer, D. Rees, P. Schafstall, J. Sherman, R. R. Stevens, Jr., T. Zaugg, G. E. McMichael, J. Sheikh, and T. Taylor, “Installation of a cw Radiofrequency Quadrupole Accelerator at Los Alamos”, Proceedings of the 1994 International Linac Conference, Tsukuba, Japan (Aug. 1994), 149.

[5] G. M. Arbique, B. G. Chidley, G. E. McMichael, and J. Y. Sheikh, “Beam Parameter Measurements on the cw RFQ1-1250 Accelerator”, 1992 Linear Accelerator Conf. Proc., Ottawa, Ontario, Canada, AECL-10728, (Aug. 1992), 55.

[6] J. David Schneider, “Operation of the Low-Energy Demonstration Accelerator: the Proton Injector of APT”, these conference proceedings.

[7] J. Bolme, et. al., “A dc Proton Injector for Use in High-Current cw Linacs”, Proc. of the 1998 European Particle Accelerator, Stockholm, Sweden, (June, 1998), to be published.

[8] J. Sherman, et. al., “Development and Test Results of the Low-Energy Demonstration Accelerator Proton Injector on a 1.25 MeV cw Radio Frequency Quadrupole”, XIX International Linac Conference Proc., Chicago, Illinois, (Aug. 1998), to be published.

[9] J. D. Sherman, et al, “Status Report on a dc 130 mA, 75 keV Proton Injector” Rev. Sci. Instrum. 69(2), (1998), 1003.

[10] Jack E. Boers, “An Interactive Version of the PBGUNS Program for the Simulation of Axisymmetric and 2-D, Electron and Ion Beams and Guns”, Proceedings of the 1995 Particle Accelerator Conference, Dallas, Texas, IEEE Catalog Number 95CH35843, (May, 1995), 2312.

[11] R. Geller, Electron Cyclotron Resonance Ion Sources and ECR Plasmas, Institute of Physics Publishing, (1996), 267.

[12] A. J. T. Holmes and M. Inman, “Development of a High-Brightness Ion source”, Proc. of the 1979 Linear Accelerator Conference, Montauk, NY, BNL 51134, (Sept. 1979), 424.

[13] Paul Allison, Joseph D. Sherman, and H. Vernon Smith, Jr., “Comparison of Measured Emittance of an H^- Beam with a Simple Theory”, unpublished Los Alamos Report, LA-8808-MS.

[14] Terence Taylor and Jozef F. Mouris, “An Advanced High-Current Low-Emittance dc Microwave Proton Source”, Nuclear Instrum. And Methods in Phys. Res., A 336 (1993), 1.

[15] H. Vernon Smith, Jr., et. al., “Comparison of Beam Simulations with Measurements for a 1.25-MeV, CW RFQ”, XIX International Linac Conference Proc., Chicago, Illinois, (Aug. 1998), to be published.

[16] K. R. Crandall and D. P. Rusthoi, Los Alamos National Lab Report LA-UR-90-4146 (1990).

[17] David W. Doll, “Three Beam Stops for APT”, Bull. Of the Amer. Phys. Soc., 43(2) (1998), 1105.