COMMISSIONING RESULTS FROM THE LOW-ENERGY DEMONSTRATION ACCELERATOR (LEDA) RADIO-FREQUENCY QUADRUPOLE (RFQ)*

H. Vernon Smith, Jr., T. L. Figueroa, J. D. Gilpatrick, W. P. Lysenko, P. M. McGehee, D. E. Rees, A. H. Regan, L. J. Rybarcyk, J. D. Schneider, M. E. Schulze,[a] J. D. Sherman, and L. M. Young,
LANL, Los Alamos, NM 87545, USA

Abstract

The LEDA RFQ is a 100% duty factor (CW) linac that delivers >100 mA of H^+ beam at 6.7 MeV. The 8-m-long, 350-MHz RFQ structure accelerates a dc, 75-keV, 110-mA H^+ beam from the LEDA injector with ~94% transmission. After the ~200-μsec-long turn-on transient, RFQ output beams with currents >90 mA have RFQ transmission that is ~10% lower than the PARMTEQM prediction. Raising the rf cavity field level to 105-110% of the design field increases the RFQ transmission to the design value. Preliminary analysis of the 93-mA quad-scan data suggests the RFQ output beam rms emittance, $\varepsilon_x \approx 0.25\ \pi$ mm mrad (normalized), is less than the measurement error away from the design, 0.23 π mm mrad.

1 INTRODUCTION

The LEDA RFQ [1,2] is a 100% duty factor (CW) linac that delivers >100 mA of H^+ beam at 6.7 MeV [3,4]. The 8-m-long, 350-MHz RFQ structure [5] accelerates the dc, 75-keV, 110-mA H^+ beam from the LEDA injector [6] with ~94% transmission. The primary objective of LEDA is to verify the design codes, gain fabrication knowledge, understand beam operation, measure output beam characteristics, learn how to minimize the beam-trip frequency, and improve prediction of costs and operational availability for the full 1000- to 1700-MeV APT accelerator. Preliminary RFQ commissioning results for pulsed beams with low currents, low repetition rates, and short pulse lengths are given in Ref. [7]. This paper gives the LEDA RFQ commissioning results obtained after the initial high-current pulsed and CW operation described in [3] and [4].

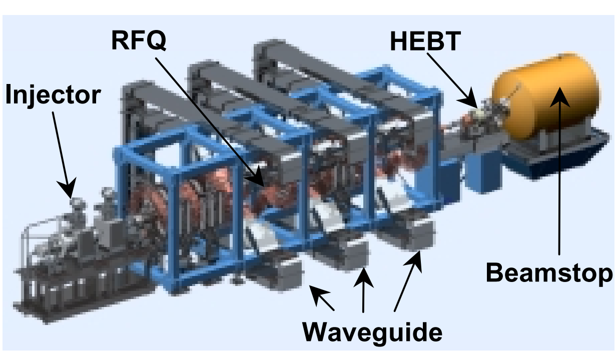

Figure 1. LEDA configuration for RFQ commissioning.

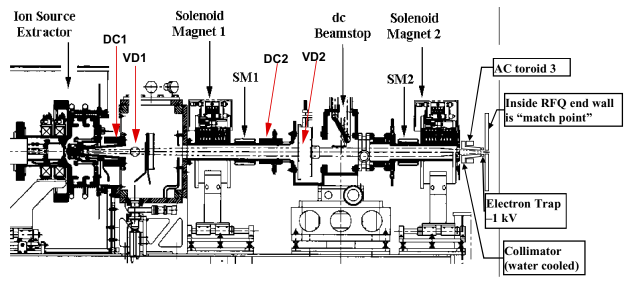

Figure 2. The LEBT beamline with optics and diagnostics.

2 LEDA CONFIGURATION

The accelerator configuration for beam commissioning of the LEDA RFQ is shown in Fig. 1 [2-4]. Major subsystems are the injector [6], ion source and low-energy beam transport (LEBT); RFQ [4,5]; high-energy beam transport (HEBT) [8]; and the beamstop [9]. The injector (Fig. 2) matches the 75-keV, 110-mA dc proton beam into the RFQ. Simulations, based on offline measurements, indicate the rms normalized emittance of the RFQ input beam is ≤0.23 π mm mrad [6]. A current modulator feeding the microwave magnetron provides beam pulsing [10] for commissioning and beam-tuning activities. The LEBT diagnostics include a pulsed-current toroid, located directly before the RFQ (AC toroid 3), that is used in determining the RFQ transmission.

Figure 3 shows the LEDA RFQ configuration. Unique features of this RFQ [5, 11-12] include its long physical length (8 m), high output energy (6.7 MeV), large beam power (670 kW), and structure cooling required (1.5 MW). Constructed as an all-brazed, 100% copper (OFE)

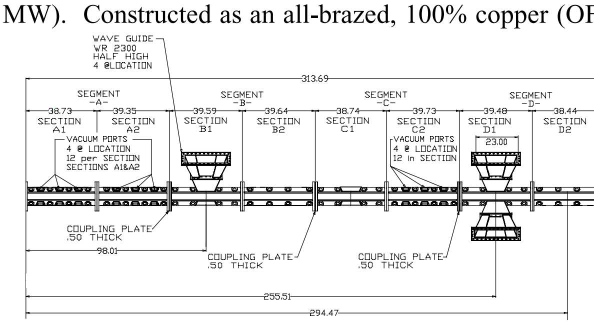

Figure 3. LEDA RFQ configuration.

---
* Work supported by the US Department of Energy.

[a] General Atomics, Los Alamos, NM 87544 USA.

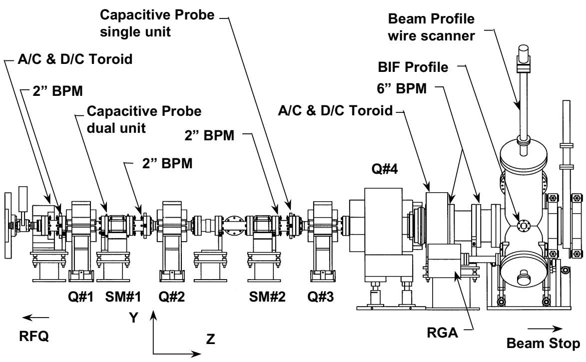

Figure 4. Layout of HEBT beamline optics and diagnostics. Beam direction is from left to right.

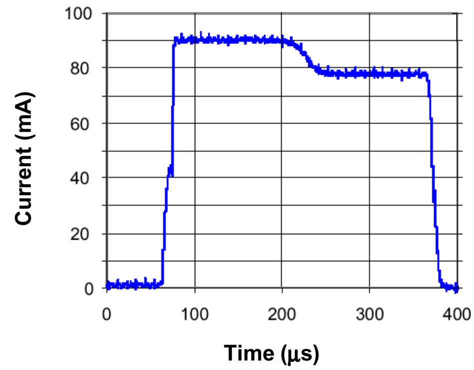

Figure 6. RFQ output beam current vs. time into a 300-μsec long pulse for the design RFQ rf-field level.

structure, it is assembled from eight 1-m-long sections. Two 1-m sections are joined to form a segment. Adjoining 2-m-long segments are resonantly coupled together to form the 8-m-long RFQ. Of the eight sections, two are used for 350-MHz rf power feed [13] via six 350-kW coupling irises and three sections provide vacuum pumping. The six 350-MHz rf vacuum windows have been tested at power levels >950 kW [14]. During operation, these windows are run at power levels up to 360 kW each. Each section includes 16 static slug tuners, used only for tailoring the initial field distribution. When in operation, its only active resonance control is by modulation of the input water temperature [4,15]. A complete description of the LEDA RFQ, including the RFQ rf-field tuning procedure, resonance control, and initial beam measurement results, is given in Refs. 4 and 16.

A schematic of the LEDA HEBT showing the location of beamline optics and diagnostics is given in Fig. 4. The function of the LEDA HEBT is to characterize the properties of the beam and transport the beam with low losses to a shielded beamstop. The beamline optics consist of four quadrupoles and two X-Y steering magnets.

The HEBT beam diagnostics [17] allow pulsed-beam-current, dc-beam-current, and bunched-beam-current as well as transverse centroid, longitudinal centroid (i.e., beam energy from time-of-flight and beam phase), and transverse beam profile (wire scanner and beam-induced fluorescence) measurements. The 6.7-MeV, 100-mA RFQ output beam impinges on a nickel ogive beamstop [9] that is mounted inside an aluminum vessel containing water to shield against prompt neutrons.

3 BEAM COMMISSIONING RESULTS AND DISCUSSION

At the time of the November 1999 Physics of High-Brightness Beams Workshop [3,4], a RFQ output CW beam current of 100 mA and RFQ transmission of 94% had been achieved. Since that time we have accumulated >30 hr of LEDA RFQ operation with at least 100 mA of CW output beam current and >70 hr with at least 90 mA of CW output beam current. For one run of 116 min (Fig. 14 of Ref. 4), most of the beam interruptions were 1-6 s in duration (Fig. 5). Recovery from these interruptions, most of them arising from short-duration injector sparks, was automatic (no operator intervention).

We find that during pulsed beam operation for RFQ rf-field levels at the design value, for pulse lengths >200 μs, and for RFQ output beam currents >90 mA, the RFQ transmission drops abruptly about 100 μs into the beam pulse. The transmission then appears to remain constant at the lower value for the duration of the pulse, including CW operation. The RFQ output beam current for a 300-

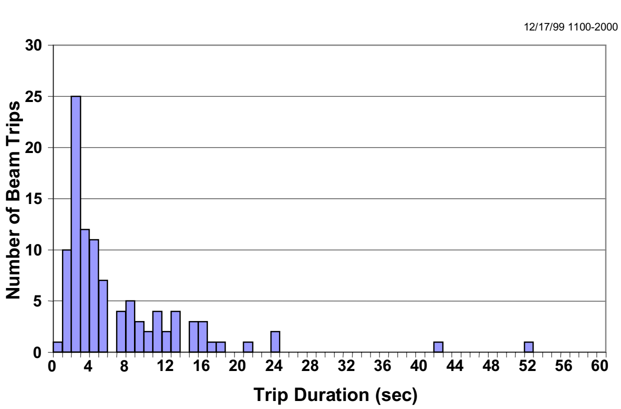

Figure 5. The number of beam trips vs. trip duration (data archived in 1 s intervals) for the 116 min run.

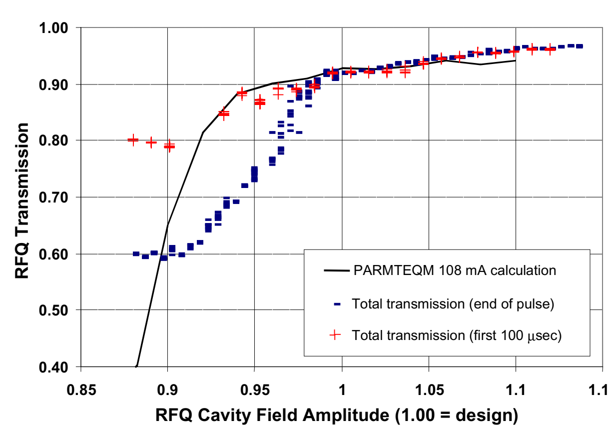

Figure 7. RFQ total and accelerated beam transmission vs. rf cavity field level at the start (crosses) and at the end (dashes) of a 500-μs-long, 90-mA beam pulse.

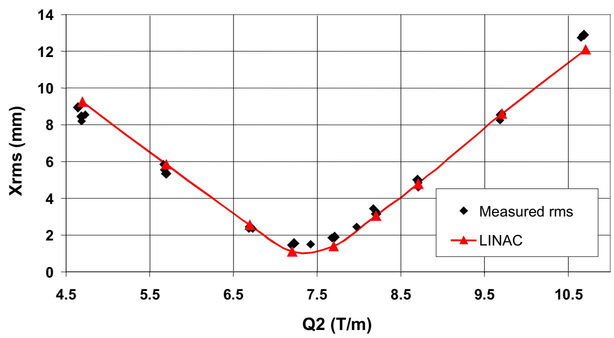

Figure 8. 93-mA x-scan data (diamonds) taken three different days. The LINAC calculation (triangles, line) has Twiss parameters as described in the text.

μsec-long beam pulse is shown in Fig. 6. About 125 μsec into the pulse the current abruptly drops by ~10%. Figure 7 shows the measured values for the total beam transmission at the start and end of a 500-μs, 2-Hz, 90-mA beam pulse. At the end of the pulse the total transmission deviates from the PARMTEQM prediction for 108-mA output beam current over the field-level range 88-98% of the design (Fig.7). The total transmission at the start of the pulse follows the PARMTEQM prediction for the range 0.91-1.1 of the design rf-field level. For output beam currents >90 mA, e.g. 100 mA, the RFQ trans-mission over the whole pulse is increased to the design value by increasing the rf-field level to 105-110% of the design field. Both the rf power system and the RFQ cooling system allow this increase - the only drawback is that the RFQ requires 10-20% more input power. These measurements will be described in more detail in [18].

The LEDA RFQ output beam emittance is measured [19] using the quadrupole-magnet scan technique [19,20]. Preliminary analysis, using the LINAC beam-optics code, of three x quad scans for a 93-mA pulsed beam is shown in Fig. 8: the RFQ output beam Twiss parameters used in the LINAC HEBT model are α_x = 1.8, β_x = 36 cm, and ε_x = 0.25 π mm mrad (normalized) [19]. The 0.23 π mm mrad rms emittance predicted by PARMTEQM for a 100-mA RFQ output beam is within the error bars of the quad-scan emittance measurement. For the nominal HEBT tune, LINAC predicts the beam emittance grows in the HEBT by 30% in the transport from the RFQ to the beamstop [8]. LINAC and IMPACT, beam-optics codes that includes non-linear space-charge effects, are both being used to analyze the quad scan data [19,20].

4 SUMMARY

The LEDA RFQ has operated with 100-mA CW output beam for over 30 hr cumulative: it has operated >70 hr cumulative with ≥90-mA CW output beam. Analysis of the data presented in this paper continues. Further commissioning results will be published in [16, 18-20]. We are now preparing to intentionally introduce and measure the beam halo in a 52-magnet FODO lattice [21,22].

REFERENCES

[1] J. D. Schneider, "Overview of High-Power CW Proton Accelerators," this conference.

[2] J. D. Schneider, "Operation of the Low-Energy Demonstration Accelerator: the Proton Injector for APT," Proc. PAC99 (New York, 29 March - 2 April 1999) pp. 503-507.

[3] H. V. Smith, Jr., *et al.*, "Update on the Commissioning of the Low-Energy Demonstration Accelerator (LEDA) Radio-Frequency Quadrupole (RFQ)," Proc. 2nd ICFA Advanced Accelerator Workshop on the Physics of High-Brightness Beams (Los Angeles, 9-12 November 1999) (in press).

[4] L. M. Young, *et al.*, "Low-Energy Demonstration Accelerator (LEDA) Radio-Frequency Quadrupole (RFQ) Results," *ibid.* (in press).

[5] D. Schrage *et al.*, "CW RFQ Fabrication and Engineering," Proc. LINAC98 (Chicago, 24-28 Aug. 1998), pp. 679-683.

[6] J. Sherman *et al.*, "Status Report on a dc 130-mA, 75-keV Proton Injector," Rev. Sci. Instrum. **69** (1998) pp. 1003-8.

[7] K. F. Johnson *et al.*, "Commissioning of the Low-Energy Demonstration Accelerator (LEDA) Radio-Frequency Quadrupole (RFQ)," Proc. PAC99 (New York, 29 March - 2 April 1999) pp. 3528-3530.

[8] W. P. Lysenko *et al.*, "High Energy Beam Transport Beamline for LEDA," Proc. LINAC98 (Chicago, 24-28 August 1998) pp. 496-498.

[9] T. H. Van Hagan *et al.*, "Design of an Ogive-Shaped Beamstop," Proc. LINAC98 (Chicago, 24-28 August 1998) pp. 618-620.

[10] T. Zaugg *et al.*, "Operation of a Microwave Proton Source in Pulsed Mode," Proc. LINAC98 (Chicago, 24-28 August 1998) pp. 893-895.

[11] L. M. Young, "An 8-meter-Long Coupled Cavity RFQ Linac," Proc. LINAC94 (Tsukuba, 21-26 August 1994) pp. 178-180.

[12] L. M. Young, "Simulations of the LEDA RFQ 6.7-MeV Accelerator," Proc. PAC97 (Vancouver, 12-16 May 1997) pp. 2752-2754.

[13] D. Rees *et al.,* "Design, Operation, and Test Results of 350 MHz LEDA RF System," Proc. LINAC98 (Chicago, 24-28 August 1998) pp. 564-566.

[14] K. Cummings *et al.*, "Results and Lessons Learned from Conditioning 1-MW CW 350-MHz Coaxial Vacuum Windows," Proc. LINAC98 (Chicago, 24-28 August 1998) pp. 938-940.

[15] A. H. Regan *et al.*, "LEDA LLRF Control System Performance: Model and Operational Experience," Proc. PAC99 (New York, 29 March - 2 April 1999) pp. 1064-1066.

[16] L. M. Young *et al.*, "High Power Operations of LEDA," Proc. LINAC2000 (Monterey, 21-25 August 2000) (to be published).

[17] J. D. Gilpatrick *et al.*, "Beam Diagnostic Instrumentation for the Low-Energy Demonstration Accelerator (LEDA): Commissioning and Operational Experience," this conference.

[18] L. J. Rybarcyk *et al.*, "LEDA Beam Operations Milestone and Observed Beam Transmission Characteristics," Proc. LINAC2000 (Monterey, 21-25 August 2000) (to be published).

[19] M. E. Schulze *et al.*, "Beam Emittance Measurements of the LEDA RFQ," *ibid.* (to be published).

[20] W. P. Lysenko *et al.*, "Determining Phase-Space Properties of the LEDA RFQ Output Beam," *ibid.* (to be published).

[21] P. L. Colestock *et al.*, "The Beam Halo Experiment at the LEDA Facility: a First Test of the Core-Halo Model," *ibid.* (to be published).

[22] T. P. Wangler, "Beam Halo in Proton Linac Beams," *ibid.* (to be published).