Proceedings of the Linear Accelerator Conference 1990, Albuquerque, New Mexico, USA

BEAM PERFORMANCE AND MEASUREMENTS ON THE RFQ1 ACCELERATOR*

G.M. Arbique, B.G. Chidley, M.S. de Jong,
G.E. McMichael and J.Y. Sheikh
AECL Research, Chalk River Laboratories
Chalk River, Ontario, Canada K0J 1J0

Abstract

RFQ1 comprises a 50 keV dc injector and a cw radiofrequency quadrupole (RFQ) accelerator. The structure, designed to accelerate 75 mA of protons to an energy of 0.6 MeV, is a test bed for a wide range of high-power RFQ experiments. The injector has delivered 100% of the design current to the RFQ. The RFQ has accelerated up to 90% of design current at 1.5 Kilpatrick. A summary of beam performance is presented and measurements are reported on the emittance and beam energy.

Introduction

RFQ1[1] is an accelerator research project at Chalk River to develop high-current cw RFQ's suitable for industrial applications such as neutron sources and fissile fuel breeding. RFQ1 comprises a 50 keV dc injector and a cw radiofrequency quadrupole accelerator. The injector is designed to provide a matched 50 keV multi-beamlet proton beam, variable up to 90 mA, to the RFQ. The RFQ is a 100% duty factor radiofrequency quadrupole, designed to accelerate 75 mA of protons to a final energy of 600 keV.

Since commissioning, in mid-1988, the RFQ1 has accelerated up to 90% of design current. Attempts to achieve the design RFQ injection current with a three-aperture source were unsuccessful. A higher current four-aperture source has replaced the three-aperture source and a modification has been made to a beam-limiting aperture in the injector to provide the design injection current.

After a brief description of the accelerator facility, efforts to achieve the design beam performance are summarized and emittance and energy measurements of the RFQ output beam are reported.

Description

Figure 1 shows a drawing of the injector and RFQ subsystems.

The major components of the injector are an ion source and low-energy beam-transport system (LEBT). The ion source, a duoPIGatron,[2] provides high currents with modest proton fractions (30%-40%). The LEBT includes a 60° dipole magnet to separate the unwanted molecular species from the beam. Solenoids, after the source and at the RFQ entrance, match the ion source beam to the RFQ acceptance.

*This work was partially supported by Los Alamos National Laboratory under contract No. 9-X5D-7842D-1.

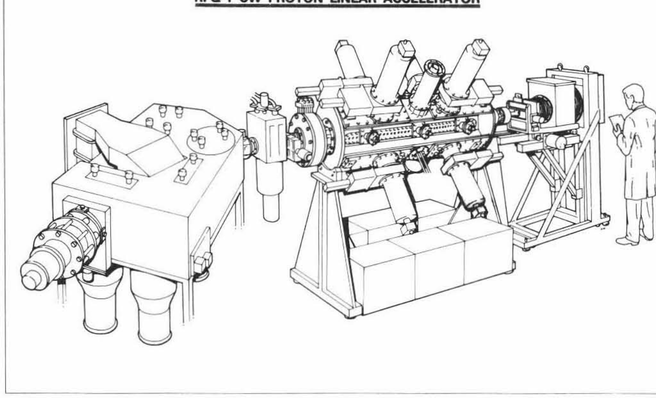

Fig. 1. RFQ1 Accelerator Components and Layout.

The accelerator is a cw four-vane loop-coupled RFQ, resonant at 267 MHz. It is constructed of mild steel, 1.5 m in length, with internal surfaces electroplated with about 100 microns of copper. Vane tips are of OFHC copper and are brazed to the vane bodies. The mean bore radius, R_0, is 4.13 mm. At the design peak electric fields of 1.5 Kilpatrick[3] (24.7 MV/m) the cavity power is 130 kW (90 kW/m) and heat fluxes on the tank walls and vane sides are $\approx$ 7 W/cm^2.

Beam Performance

The RFQ was designed using the code PARMTEQ.[4] At 1.5 Kilpatrick, a 90 mA 0.05 π-cm-mrad normalized rms emittance beam (design 3-beamlet injection) should have 85% transmission (75 mA output current). At injection currents less than 50 mA (i.e., lower space-charge) transmissions in excess of 90% are predicted.

Transmission levels measured during the initial low-current commissioning runs on RFQ1[5,6] were much lower than predicted ($\approx$ 35% for three-beamlet injection). A deficiency in the RFQ entrance solenoid current, and misalignment of LEBT elements, prevented a good match to the RFQ acceptance. With improved focusing and better alignment, transmissions in excess of 90% were achieved for single beamlet injection, and cw currents of up to 15 mA were accelerated.

Attempts to achieve the design injection current with the three-aperture source were unsuccessful. Operating the source in the matched condition (minimum beam divergence, and hence minimum emittance), about 50 mA of proton beam could be transported to the RFQ, with 85% transmission through the accelerator. Figure 2 shows the injector and RFQ output currents (measured with non-intercepting beam current monitors) for a three-beamlet operation. An aperture on the plunging beam stop (PBS), at the exit of the injector (past the injector beam current monitor), acts to limit the beam size. Since the beam is nearly parallel at this location, the aperture acts as an emittance scraper. Operated "over match", the source could produce proton current in excess of 90 mA, but the PBS aperture limited the current transported to the RFQ, and RFQ output current reached a plateau of about 55 mA.

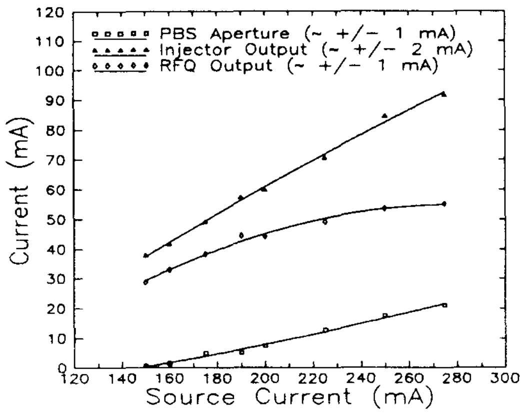

Fig. 2. Three-Beamlet Injection Transmission Currents.

Two main limitations prevented us from achieving the design injection current with the three-aperture source. It was originally planned to use an extraction column gap of 5 mm, but this gap is too small for reliable operation. At 6.4 mm, the smallest gap used to-date, the extraction column spark rate averages about one per hour, a rate considered maximum tolerable for reliable operation. The second limitation was in the plunging beam stop aperture, which intercepted about 15% of the proton current at match. Calculations with the code TRANSOPTR[7] indicate that it was undersized for a three-beamlet beam.

To achieve higher current, a four-aperture extraction column was installed with an estimated emittance 15% larger than the three-beamlet source. To accommodate the larger beam, the PBS aperture diameter was increased by 25%. Four-beamlet operation results are preliminary, but, at match, about 70 mA of protons can be transported to the RFQ, with loss on the PBS of about 10%. Operating the source "over match", the design current of 90 mA can be exceeded. Under these conditions, up to 67 mA (90% design) was accelerated through the RFQ.

Figure 3 shows RFQ transmission for three-beamlet and four-beamlet operation as a function of relative matched source-current. Transmission is an optimum for matched source-current (i.e., minimum source emittance), and due to beam scraping on the PBS aperture, the transmission curves are fairly broad. The 85% peak transmission for three-beamlet injection is in good agreement with the PARMTEQ prediction. As expected, the transmission for four-beamlet injection (i.e., higher current, larger emittance) is decreased; the highest transmission measured to date is about 80%.

Figure 4 shows the RFQ transmission versus the vane-tip field for three-beamlet injection. At 1.2 Kilpatrick, transmission is down to 70% from 85% at the 1.5 Kilpatrick design field. PARMTEQ

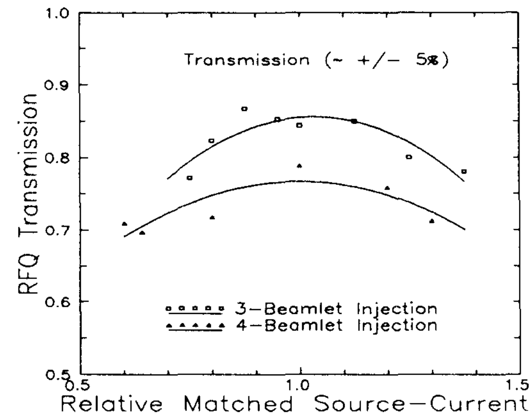

Fig. 3. RFQ Multi-Beamlet Transmission.

predicts that transmission can be increased by operating at higher fields. However, an rf overheating problem at the ends of the vane-seal-gaskets prevents us from further increasing the fields at this time.

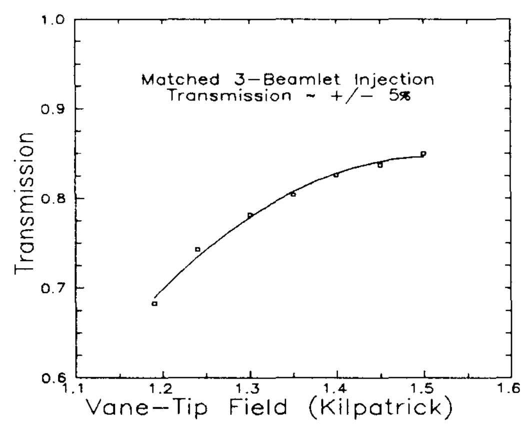

Fig. 4. RFQ Transmission vs. RF Vane-Tip Field.

RFQ Output Beam Measurements

Figure 5 shows the transverse phase-space of the RFQ output beam for matched three-beamlet injection, measured in the horizontal plane of the injector 60° bend magnet. The emittance is 0.04 π-cm-mrad, and the distribution shows no signs of the original three beamlets. We do not have a measurement of the injector output emittance, but, from ion source test stand measurements, and RETICON[8] measurements on the injector, we estimate our source emittance to be slightly less than 0.04 π-cm-mrad. The similarity of the source and RFQ output emittance does not necessarily indicate zero emittance growth in the LEBT and RFQ. We expect some growth in effective emittance in the LEBT, but the PBS aperture acts as a beam scraper, to limit the emittance of the injected beam.

Figure 6 shows the RFQ on-axis energy spectrum for matched three-beamlet injection at design and 1.2 Kilpatrick vane-tip fields. The measurements were made using a 45° bend, magnetic energy-

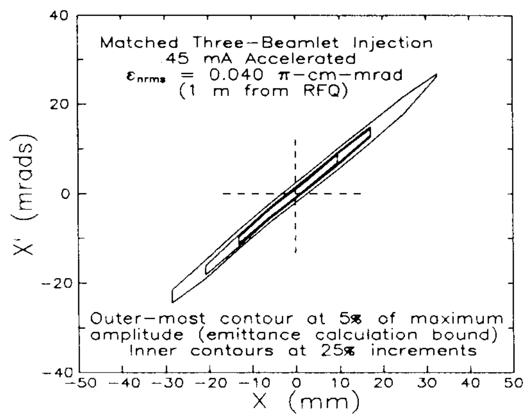

Fig. 5. RFQ Output Beam Transverse Phase-Space for Matched Three-Beamlet Injection.

analysis system with an energy resolution of about 0.2%. With design field in the RFQ, the spectrum is characterized by a single peak at 600 keV with a width of about 50 keV. Lower energy peaks are present in the spectrum; however, they are reduced in intensity by over three orders of magnitude. At reduced fields, the transmission decreases and the energy spectrum shifts to lower energies. At 1.2 Kilpatrick, the main peak width at half-maximum is decreased by about 1/3 and the base is broadened on the low-energy side. Lower energy peaks in the spectrum are increased in magnitude; the most prominent at 360 keV has a height close to 70% of the 600 keV peak, although it is narrow, with a width of less than 10 keV.

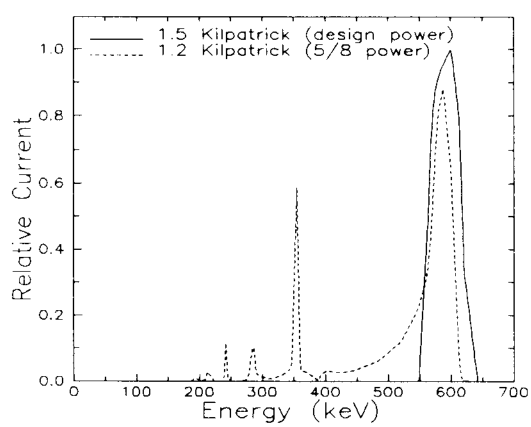

Fig. 6. RFQ Energy Spectrum.

Summary and Discussion

RFQ1 has accelerated up to 90% of the design current. A higher current four-beamlet source was installed on the injector when the design current could not be achieved with the three-aperture source. The four-beamlet emittance is larger than the design acceptance and beam transmission through the RFQ structure is about 5% less than the 85% target.

Emittance measurements have been made on the RFQ output beam for three-beamlet injection. The measured output emittance was in good agreement with the source emittance. Emittance growth in the system is limited by beam scraping on the PBS aperture.

The energy spectrum of the RFQ, at design power, is characterized by a single peak at 600 keV with a width of 50 keV. At low power the transmission decreases due to decreased longitudinal acceptance. The energy spectrum shifts to lower energy and lower energy peaks become more prominent.

Acknowledgements

The authors gratefully acknowledge the efforts of numerous persons involved in the RFQ1 project. In particular: L.F. Birney, A.D. Davidson, and M.H. Thrasher, who operate and maintain the accelerator and systems; A.B. Hood and B.H. Smith for electronics support; and W.L. Michel for work on the system diagnostics.

References

1. G.M. Arbique et al., "Commissioning of the RFQ1 Injector", Proc. IEEE Particle Accelerator Conference, Washington D.C., March 16-19, 1987.

2. M.R. Shubaly and M.S. de Jong, "High Current DC Ion Beams", IEEE Trans. Nucl. Sci. NS 30, No. 2, (1983).

3. W.D. Kilpatrick, "Criterion for Vacuum Sparking Designed to Include both RF and DC", Rev. Sci. Instr., Vol 28, No. 10, Oct 1957.

4. K.R. Crandall and T.P. Wagner, "PARMTEQ - A Beam Dynamics Code for the RFQ Linear Accelerator", Proc. Workshop on Linear Accelerator and Beam Optics Codes, San Diego, CA, Jan 19-21, 1988, AIP Conf. Proc. No. 177,22.

5. G.M. Arbique et al., "CW Operation and Initial Beam Experiments with the RFQ1 Accelerator", 1988 Linear Accelerator Conf. Proc., CEBAF, Newport News, Va, Oct 3-7, 1988.

6. G.E. McMichael et al.,"Exploring the Beam Parameter Space of a CW RFQ Proton Accelerator", Proc. 1989 Particle Accelerator Conf., Chicago, IL, Mar 20-23,1989.

7. E.A. Heighway and M.S. de Jong, "TRANSOPTR - A Beam Transport Design Code with Space Charge, Automated Internal Optimization and General Constraints", AECL-6975, Rev. A, June 1984, Atomic Energy of Canada Limited, Research Company, Chalk River, Ontario, K0J 1J0.

8. B.G. Chidley et al.,"RFQ1 Diagnostic Devices", these proceedings.