CW OPERATION AND INITIAL BEAM EXPERIMENTS WITH THE RFQ1 ACCELERATOR*

G.M. Arbique, B.G. Chidley, G.E. McMichael, and J.Y. Sheikh
Atomic Energy of Canada Limited, Research Company
Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada K0J 1J0

Abstract

The RFQ1 accelerator is a 4-vane cw radiofrequency quadrupole designed to accelerate 75 mA of protons to 600 keV. The accelerator is the major component of a program at the Chalk River Nuclear Laboratories (CRNL) to study design, construction, control and diagnostics techniques for high current cw RFQ's. RF conditioning to 1.5 Kilpatrick was completed and first cw proton beam accelerated in July 1988. This paper describes the current status of the accelerator, and the initial beam experiments.

Introduction

The RFQ1 facility at CRNL[1,2] is a test bed for the development of 100% duty-factor high-current Radio-Frequency Quadrupole proton accelerators. The project is intended to demonstrate design, construction and operational technology. CRNL's interest in this field is centred on developing the accelerator technology to build fissile fuel breeders, intense neutron sources, and neutral beam injectors for fusion reactors.

The experimental program will cover a wide range of RFQ experiments. Investigations will include: voltage gradient limits in the RFQ1 cavity, beam space parameters of transmitted beams from single and multi-aperture proton sources, tolerances on RFQ vane position, and rf field tuning in RFQ cavities. Results will be correlated with RFQ field modelling and beam dynamics codes.

RF conditioning of the accelerator has been completed up to the cw design field of 1.5 Kilpatrick. Low-current proton beams have been accelerated, although transmission is significantly less than the 80%-90% design target. This paper will discuss the rf conditioning of the accelerator and the present status of beam-current measurements.

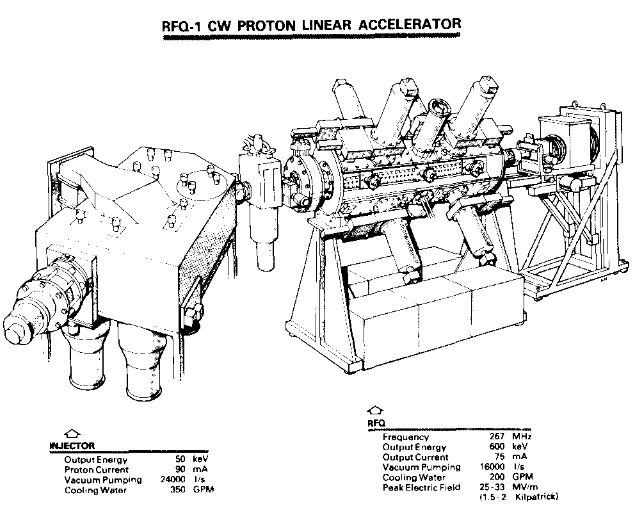

Figure 1: Accelerator components and layout.

*This work was partially supported by Los Alamos National Laboratory under contract #9-X5D-7842D-1.

Description of Facility

The RFQ1 facility consists of two subsystems, the injector and the RFQ. Figure 1 is a schematic of these subsystems and Table 1 summarizes the design parameters for the facility.

The injector incorporates a 50 keV 3 aperture duoPIGatron source and LEBT to channel a proton beam to the accelerator. By mixing argon with the hydrogen primary-gas feed, source proton current can be smoothly varied up to 90 mA, while maintaining a matched beam with good emittance (the duoPIGatron normalized rms emittance is ~ 0.04 pi cm-mrad).

The LEBT consists of a focusing solenoid and a 60° bending magnet, to separate unwanted ion species, in a common vacuum chamber. Control of the LEBT chamber residual-gas pressure optimizes space-charge neutralization during transport. A second focusing solenoid at the RFQ entrance matches the beam emittance to the accelerator acceptance.

Table 1: RFQ1 Design Parameters

Particle	Protons
Output Energy	50 keV dc (injector) 600 keV (RFQ)
Output Current	240 mA dc (total ion source) 90 mA dc (injector protons) 75 mA (protons RFQ)
Duty Factor	100%
RF	267 MHz
Peak Electric Field	1.5 * Kilpatrick (design) 2.0 * Kilpatrick (thermal limit)
RFQ length	1.5 m
RFQ Bore (r_o)	4.13 mm

The accelerator is a high-current 600 keV 267 MHz RFQ designed to deliver cw current up to 75 mA. The design intervane voltage is 78 kV, giving peak surface fields of 25 MV/m or 1.5 Kilpatrick. The accelerator cavity and vanes are constructed of copper-plated carbon steel with internal water-cooling channels. The vane tips are solid OFHC copper and were brazed to the vanes, machined and then masked during copper plating. A total of 160 holes (3.2 cm dia, length to I.D. = 1.6) provide good vacuum conductance between the cavity and eight vacuum manifolds. Machining of accelerator components was done locally and copper plating was done by GSI Darmstadt (Germany). A unique feature of RFQ1 is the copper racetrack seals that make the vacuum and rf joint between the vanes and tank, which allows vane position to be adjusted. Water-cooled vane coupling rings at either end of the vanes stabilize the segment field and fixed non-resonant end-tuner posts compensate for the detuning effects of the vane coupling rings[3]. Figure 2 shows an axial view of the RFQ1 cavity.

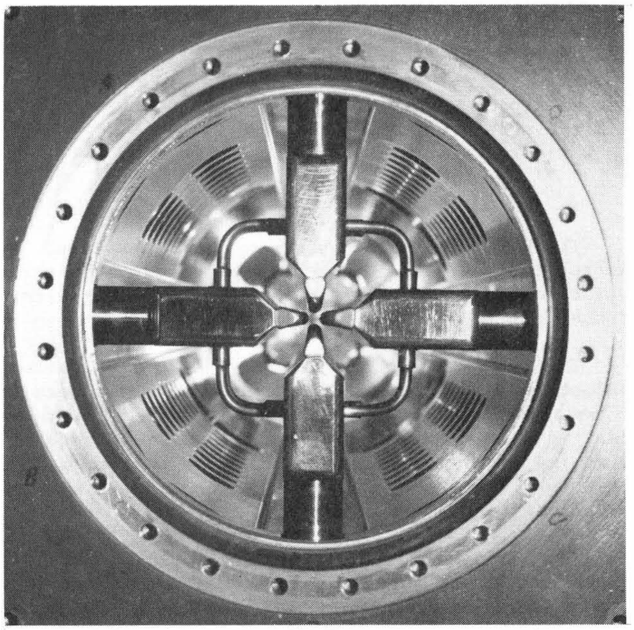

Figure 2: Axial view of RFQ1 cavity.

The rf system has a 400 kW triode final stage coupled to the cavity-drive loop through a coaxial line. The system is intended for cw operation but pulsed operation at peak powers up to 50 kW is possible. The drive loop is matched for 75 mA beam loading and is over-coupled to the unloaded tank with a reflection coefficient of 0.11 (i.e., a VSWR of 1.25).

High-Power RF Conditioning

From SUPERFISH calculations (Q = 10900) and the measured unloaded Q (Qm = 7900) it was predicted that a tank power of 135 kW was required to reach the design intervane voltage of 78 kV. An intrinsic germanium detector is used to measure the cavity bremsstrahlung emission endpoint to determine the intervane voltage. Tank power and changes in field symmetry are measured by rf inductive probes located in the cavity at two longitudinal positions in each quadrant. These loops were calibrated by feeding a low-power rf signal into the tank before it was evacuated. The existence of multipactoring levels around 5 W made low-power calibrations difficult when the tank was under vacuum.

During conditioning, progress was monitored by TV cameras, to monitor light emission from the vane tip regions, and vacuum measurement, to observe outgassing. Cameras were set up to look along the accelerator axis and to view the coupling loop. Rate of increase of rf power was limited to keep the vacuum level below 1×10^{-5} torr; above this level sparking became excessive.

As in the CRNL "sparker" experiments[4], randomly distributed glowing points were observed on the RFQ vane tips during conditioning. The number of visible glow points was dependent upon the degree of surface conditioning and power level. However, the intensity of light emission from individual glow points only seemed to be dependent on the power level. In the unconditioned tank glow points were numerous and total light intensity was high. As the tank became conditioned the number of glow points decreased. In the conditioned tank, new glow points continuously appear old ones disappear (typically over periods of hours); the rates of appearance and disappearance seem to be equal.

Sparking, during conditioning, was typically characterized by series of micro-discharges, localized near the vane tip surfaces. Occasionally, micro-discharges appeared to propagate along the vane tips. Frequently, glow points disappeared after sparks occurred. Conditioning was accelerated by pulsing rf power high enough to cause sparking. Raising cw power too rapidly resulted in intense sparking and reflected power trips on the rf drive. Multipactoring was noted in the tank at powers less than a kilowatt but was not observed in the rf drive loop. Conditioning through the multipactoring region was done in pulsed mode, after which rf could be brought on cw.

At powers less than 50 kW, conditioning was accelerated by alternating pulsed and cw operation, typically pulsing to 10%-20% in excess of cw power levels. Higher power conditioning was all cw (because of the pulsing limitations on the rf system) and continued at a slower rate. A cumulative time of approximately 50 hours was required to condition to 1.5 Kilpatrick. In the conditioned tank sparks are infrequent (typically less than two per hour) and small, and the system operates virtually trip free.

At 78 kV, as measured with the germanium detector, the tank power is 135 ± 5 kW, in excellent agreement with the predicted value. Figure 3 shows the cavity resonant frequency-shift with power, measured at constant coolant inlet temperature. The behaviour of this frequency-shift is interesting. It increases slightly before changing to a negative slope at 70 kW (at 135 kW the shift is about -5 kHz/kW). Frequency-shifts with structure temperature (measured by varying coolant inlet temperature at constant power) at 40 kW, 60 kW and 120 kW are about -6 kHz/°C, 0 kHz/°C and -10 kHz/°C, respectively. Further thermal analyses will be necessary to establish the reasons for these shifts. Nonetheless, frequency-shifts are small and power can be easily re-established in the RFQ after an rf trip, without waiting for the tank temperature to stabilize; much of the tank conditioning was done under manual frequency control, although an AFC was added during the later stages.

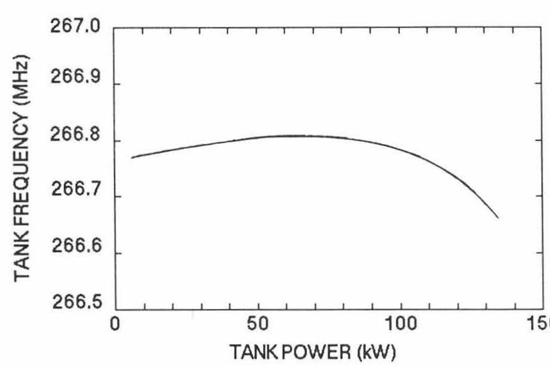

Figure 3: Frequency shift with tank power.

X-ray levels are high enough that lead shielding is necessary to prevent exposure to personnel. While the steel structure of the accelerator offers excellent attenuation of x-rays, many of the flange covers (i.e., tuner ports, vacuum manifolds) are aluminum (1" or 1/2" thick). With the accelerator operating at 1.5 Kilpatrick contact fields can exceed 10 R/h, 1 m distant from the structure nominal fields are 100 mR/h. A 6-mm-thick lead wall (about 1 m from the structure) reduces the fields to well below the 2.5 mR/h personnel exposure tolerance level.

Initial Beam Experiments

Beam experiments on the RFQ, to date, have centred on improving the transmission of the accelerator. Currents injected into the structure are measured on an intercepting beam stop and by a non-intercepting dc beam-current monitor. A four-segment beam-scraper aperture at the entrance of the RFQ indicates whether the beam is properly centred and focused. At the exit of the accelerator current is monitored on a beam stop. Calorimetry on this stop is used to correlate beam current and energy.

Proton currents of up to 6 mA have been injected into the RFQ with output currents approaching 2 mA. Vertical alinement of the structure and beam transport elements appears to be satisfactory and focusing elements have been optimized for beam transmission. At the present low injected current levels, variation of space-charge neutralization, by changing the injector pressure over a factor of three, has little effect on improving transmission. Areas currently under investigation to improve transmission include: loss of beam at the exit of the RFQ, and improper transverse phase space matching of the beam to the RFQ. As in the "sparker" experiments, glow points and sparking have been unaffected by beam loading.

Conclusions

High-power conditioning of the RFQ1 accelerator has been achieved up to the 1.5 Kilpatrick design value. Operation of the structure at high power is now trip free and the cooling system, vacuum system and vane-to-tank racetrack seals have performed well. The results of the CRNL "sparker" experiments proved to be a useful guide during rf conditioning and the observed conditioning behaviour, x-ray emission and light emission at the vane tips were similar to the behaviour observed with the much shorter "sparker" assembly.

Three beamlet proton currents of approximately 2 mA have been accelerated to 600 keV, although the transmission is much lower than expected. Installation of a high-power beam stop to permit acceleration of higher currents is nearing completion.

Acknowledgments

The authors wish to acknowledge the critical roles of L.F. Birney and A.D. Davidson in the assembly, maintenance and operation of the facility, and B.H. Smith for electronics design and support.

References

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

(2) B.G. Chidley, et. al., RF Tuning and Initial CW Operation of RFQ1, European Particle Accelerator Conference, Rome, Italy, June, 1988.

(3) R.M. Hutcheon, Low Power RF Tuning of the RFQ1 Accelerator, These conference proceedings.

(4) R.M. Hutcheon, et. al., Operation of a CW High Power RFQ Test Cavity: The CRNL Sparker, 1985 Linear Accelerator Conference, 1984 May 7-11, Seeheim/Darmstadt, Fed. Rep. of Germany.