BEAM TRANSMISSION AND EMITTANCE MEASUREMENTS ON THE RFQ1 ACCELERATOR*

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Abstract

RFQ1 is an accelerator project to develop high-proton current cw RFQ's suitable for scientific and industrial applications such as neutron sources, nuclear waste transmutation and fissile fuel breeding. The accelerator, which comprises a 50 keV dc injector and a 0.6 MeV cw radiofrequency quadrupole accelerator, is a test bed for a wide range of high-power RFQ experiments. The structure was designed to accelerate 75 mA of protons and has achieved the full design current. Measurements are reported on the output beam transmission and emittance for four-beamlet proton beam injection from a duoPIGatron ion source.

I. INTRODUCTION

The RFQ1 [1] project is a research program for the development of high-current cw radio-frequency quadrupole (RFQ) proton accelerators. The injector is designed to provide a matched 50 keV multi-beamlet dc proton current, 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 [2], the major design targets have been achieved on the RFQ1 facility, and the experimental program with the duoPIGatron source has been completed. Recent experiments were concerned with emittance and beam transmission measurements to characterize the RFQ output beam under a variety of operating conditions. A final set of experiments, using an ECR source on the injector, are reported elsewhere in these proceedings [3].

The RFQ1 vanes are being replaced to increase output energy to 1.25 MeV. To avoid confusion the 600 keV output accelerator will, in future, be referred to as RFQ1-600 and the new version as RFQ1-1250.

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II. DESCRIPTION

Figure 1 shows an artist's representation of the injector and RFQ subsystems.

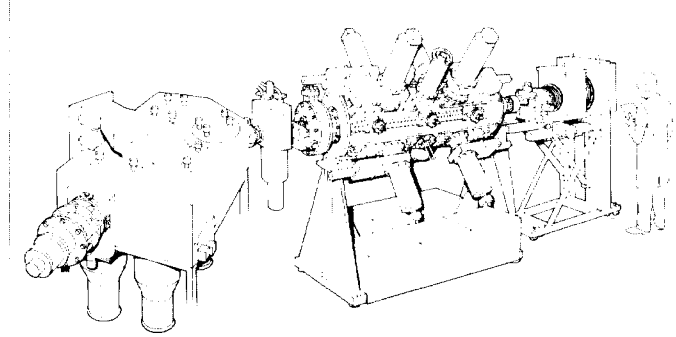

Figure 1 RFQ1 accelerator components and layout.

The major components of the injector are an ion source and low-energy beam transport system (LEBT). For the purposes of this paper the ion source is a duoPIGatron [4], providing high currents with modest proton fractions (30%-35%). 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. A plunging beam stop (PBS) at the exit of the injector is used for beam set-up, and is raised to inject beam to the RFQ.

The accelerator is a cw four-vane type RFQ, resonant at 267 MHz. The mean bore radius is 4.13 mm. At the design peak electric fields of 1.5 Kilpatrick [5] (24.7 MV/m) the intervane voltage is 78 kV.

III. BEAM TRANSMISSION

The PARMTEQ [6] code predicts 85% transmission (75 mA output current) for a 90 mA 0.05 π-cm-mrad emittance input beam. At injection currents less than 50 mA (i.e., lower space-charge) transmissions in excess of 90% are predicted. Attempts to achieve the design 75 mA RFQ output current with a three-aperture source on the RFQ1 injector were unsuccessful, because the source could not supply enough current [7]. With the installation of a higher-current four-aperture duoPIGatron, with 15% higher emittance, the 75 mA RFQ design current was achieved.

The best match of the injector LEBT beam to the RFQ acceptance is achieved when the source is operated at matched perveance. For a multi-aperture source, matched perveance is defined as the output current which yields the minimum beamlet-divergence (and hence minimum emittance). As a practical means of varying the injector current, the source is often operated off-match by varying the source plasma density. Apertures in the injector, at the injector solenoid and in the vicinity of the PBS, limit the size of the beam.

Figure 2 shows injector and RFQ output currents as a function of source current. Non-intercepting beam-current monitors measure the exit currents, and the PBS aperture, downstream of the injector exit monitor, is isolated from ground to measure intercepted current. At 250 mA the source is matched, and transmission is optimized at 80% with 50 mA accelerated current. When operating the source "over-matched", proton current in excess of the design 90 mA could be transported to the RFQ, and accelerated current approached a plateau of about 70 mA. RFQ transmission for four-beamlet injection is lower than with the three-beamlet source, due to the higher source emittance and increased PBS aperture diameter [7]. The high beam loss on the PBS aperture at high-current, is consistent with space-charge induced beam blow-up and is another factor limiting injected current to the RFQ. Beam loss mechanisms will be more fully investigated with emittance measurements on the injector output beam.

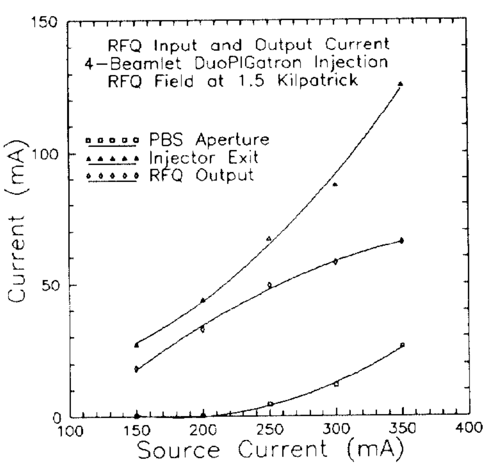

Figure 2. Injector and RFQ output currents.

Injector current may be varied, without increasing source emittance, by maintaining matched perveance while mixing argon with the source hydrogen gas feed [1]. When injected current is reduced using this method transmission increases. At one-half nominal injection current, transmission is 90%, in excellent agreement with PARMTEQ predictions.

Transmission, at high-current, could be raised by increasing the vane-tip field above the design level, but field levels in RFQ1-600 were limited due to an rf overheating problem at the ends of the vane-seal-gaskets. Nonetheless, by operating 10% above the design field level and by running source beam in excess of 350 mA, the design 75 mA current was accelerated through the RFQ, with transmission of 75% (with the more efficient ECR source [3] an accelerated current of 79 mA was achieved).

IV. RFQ OUTPUT EMITTANCE

An Emittance Measurement Unit (EMU) is used to measure the output beam emittance of the RFQ. The output beam is intercepted by a moveable water-cooled beam-stop fitted with a 5 cm long copper slit. The slit transmits a narrow portion of the beam to a Faraday cup behind a second movable slit. Slit arrangements are available for either the X,X' or Y,Y' measurements.

Figure 3 shows a typical X,X' measurement (i.e., measured in the horizontal plane of the injector 60° bend magnet) for matched beam injection at the design field. Here the emittance is 0.04 π-cm-mrad (normalized rms). The original four-beamlet distribution is no longer evident after acceleration through the RFQ. Under the same measurement conditions the Y,Y' emittance was nearly 20% larger.

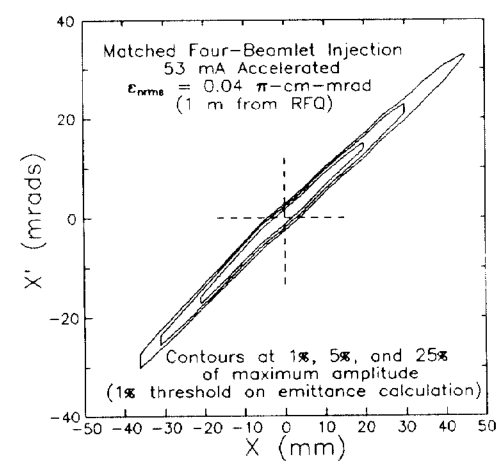

Figure 3. RFQ output emittance for four-beamlet injection.

The four-beamlet output emittance is in close agreement with the value measured for three-beamlet transmission and is less than the estimated injector emittance (based on measurements on an ion source test stand). Increasing the PBS aperture diameter and operation with the higher emittance four-aperture source had no measurable effect on the RFQ output emittance. This agrees with PARMTEQ calculations, which indicate that the RFQ acts as an emittance scraper due to beam spill at higher currents.

That the RFQ acceptance space is filled is further shown by the change in emittance when the RFQ current is varied by running the source off-match. Above 50 mA the emittance remains constant, while it increases at lower currents. The larger RFQ output beam emittance is due to reduced space-charge defocusing, also a larger emittance input beam may arise from operating the source off-match. When the injector proton current was reduced at matched perveance, by adding argon gas, the RFQ output emittance remained constant.

Reducing RFQ field also results in increased output beam emittance. At matched current injection, operation of the RFQ at 80% of the design field results in an emittance increase of about 35%, a similar decrease in transmission also occurs. The emittance increase is explained by the reduced longitudinal acceptance, which results in growth of lower-energy beam components [6]. There was no measurable change in emittance when fields were increased to 110% of design. A similar effect occurs when input beam energy is reduced. Injection at 45 kV (5 kV below design) resulted in 65% transmission (for a best match 45 mA injection beam) and a 30% emittance increase.

V. DIPOLE FIELD TILT MEASUREMENTS

The motor-driven RFQ1 tuners [8] have been used to introduce dipole field perturbations during beam operation. Tuners are situated in opposite quadrants and by inserting one and retracting the other, rf power (and hence field levels) in these quadrants can be perturbed in equal and opposite directions (adjacent quadrant fields are unperturbed). Dipole perturbations were also induced by radial movements of one vane. This raises fields in the shifted-vane quadrants and lowers fields, by an equal measure, in the quadrants opposite.

For matched four-beamlet injection, beam transmission was unaffected when quadrant fields differed by less than 8%. A measurement with a field difference of 14% showed a transmission decrease of 10%. Over the range of field imbalances investigated no change in output emittance was found. These measurement results are in good agreement with PARMTEQ predictions.

VI. SUMMARY

The experimental program on RFQ1-600 has been completed and the major design goals have been achieved. The RFQ proved to be a robust and reliable machine capable of operating up to the 1.6 Kilpatrick field level. A high tolerance to cw beam spill (> 30 mA) in the structure facilitated the measurement of beam parameters over a range of "off-optimum" operating conditions.

Measured transmission and emittance were in agreement with PARMTEQ code predictions over a wide range of operating conditions.

VII. ACKNOWLEDGEMENTS

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