TESTING THE ISAC LEBT AND 35 MHZ RFQ IN AN INTERMEDIATE CONFIGURATION

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Abstract

An 8 m long, 35 MHz 4-rod split-ring RFQ is required to accelerate exotic beams with $A/q \leq 30$ from 2 keV/u to 150 keV/u at the ISAC radioactive beam facility at TRIUMF. Noteworthy aspects of the RFQ include operation in cw mode at an rf power of 100 kW and the elimination of a bunching section in favour of an external pre-buncher in the LEBT. An initial 2.8 m section of the accelerator (7 of 19 rings) has been installed in the 8 m tank to allow rf and beam tests well in advance of the final configuration. An injector consisting of a 2.45 GHz micro-wave CUSP source, analyzing magnet and electrostatic beam transport line (LEBT) supplies the test beams. A 11.7 MHz four-harmonic sawtooth pre-buncher is installed in the LEBT. Electro-static elements positioned in the remainder of the RFQ tank transport the 53 keV/u beam to a diagnostic station downstream of the RFQ. A description of the test set-up and results of both rf tests and beam tests will be reported.

1 INTRODUCTION

A radioactive ion beam facility with on-line source and linear post-accelerator is being built at TRIUMF. [1] The accelerator chain includes a 35 MHz RFQ, operating *cw*, to accelerate beams of $q/A \geq 1/30$ from 2 keV/u to 150 keV/u.

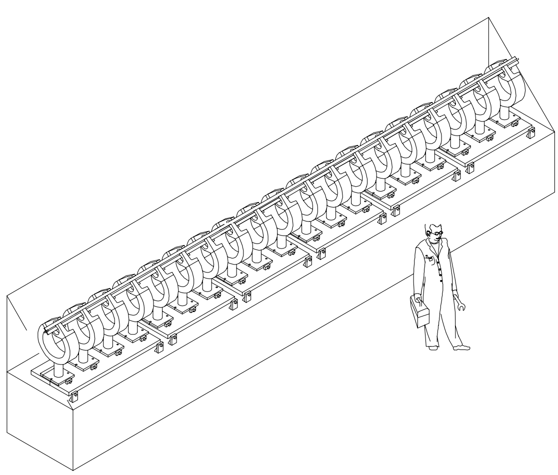

Figure 1: The ISAC 19 ring RFQ.

The ISAC RFQ (Fig. 1) is a split ring 4-rod structure[2]. A total of 19 split rings, each feeding 40 cm lengths of modulated electrode, are housed in a square 1m×1m tank with a total length of almost 8 m. The design peak inter-vane voltage is 74 kV, the maximum power is 100 kW and the bore radius is $r_o = 7.4$ mm. Both rings and electrodes are water cooled. A unique feature of the design is the constant synchronous phase of -25°[3]. The buncher and shaper sections of the RFQ have been completely eliminated in favour of a four-harmonic sawtooth pre-buncher located 5 m upstream of the RFQ in the low energy beam transport (LEBT). This shortens the structure but in addition, injecting a pre-bunched beam into the RFQ yields a smaller longitudinal emittance at the expense of a slightly lower beam capture. The pre-buncher operates at a fundamental frequency of 11.7 MHz, the third sub-harmonic of the RFQ. This introduces an 86 nsec bunch spacing into the beam that is useful for some physics experiments. We expect 81% of the beam will be accelerated in the 11.7 MHz bunches.

Prior to construction it was decided to proceed with a two-stage installation. The plan is to install and test with beam the first seven rings of the RFQ before installing the remaining twelve rings. The test allows us to perform rf measurements, establish alignment procedures, commission the injection line, determine matching conditions and establish capture efficiencies all well in advance of the final installation.

2 THE TEST SET-UP

A schematic of the test set-up is shown in Fig. 2. A copper wall is installed just downstream of the seven ring section to isolate the rf fields. Beams produced in the ISAC off-line ion source (OLIS) are transported through a ∼15 m long LEBT section to arrive at the RFQ. The beam is ac-

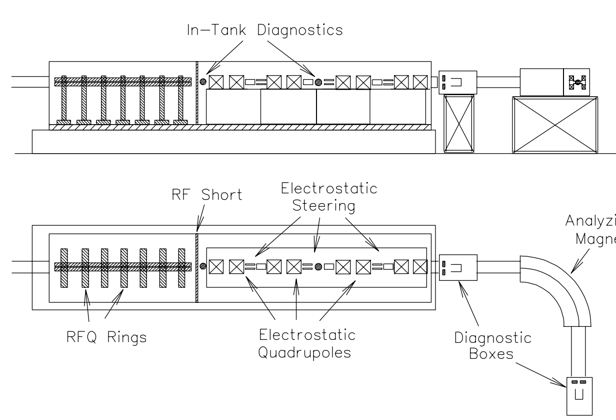

Figure 2: A schematic view of the RFQ and test station.

celerated to 53 keV/u and then a series of eight electrostatic quadrupoles transport the beam to a diagnostic station just downstream of the 8 m RFQ tank.

2.1 OLIS and LEBT Commissioning

A schematic of the ion source (OLIS) and injection line (LEBT) are shown in Fig. 3. The line was installed from July-December 1997 and commissioned in the first few months of 1998. Wire-scanners and Faraday cups are positioned throughout the line. In addition a transverse emittance rig is located after the OLIS analyzing magnet. A fast Faraday cup is located just upstream of the RFQ and was used to commission and tune the pre-buncher.

A 2.45 GHz micro-wave source with a magnetic cusp plasma confinement is installed in OLIS. The source efficiently produces positive light ions of gaseous species from Hydrogen to Argon. The test beams for the initial RFQ beam tests will be N^+, N_2^+, and Ne^+. The source sits on a high voltage platform operating from 12 kV to 60 kV to produce the required RFQ injection energy of 2 keV/u for $6 \leq A \leq 30$.

An Allison-type emittance scanner [4], designed and fabricated at TRIUMF, has been used to optimize the source and matching optics. The measured transverse emittance of the commissioning N^+ beam is shown in Fig. 4.

The LEBT consists of electrostatic elements; quadrupoles, steerers and spherical bends [5]. The tune was established with a 30 kV beam of N^+ and is consistent with theoretical tunes.

2.2 Pre-buncher Commissioning

The pre-buncher consists of two circular electrodes spaced 8 mm apart forming a single gap with a beam aperture of

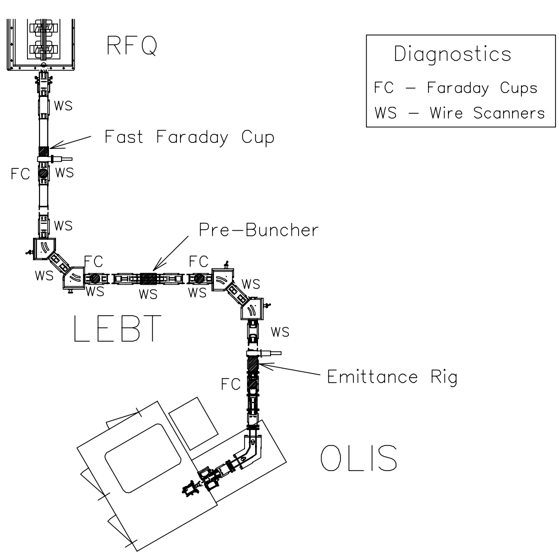

Figure 3: The layout of the off-line ion source (OLIS) and low energy beam transport (LEBT) upstream of the RFQ. The commissioning diagnostics are indicated.

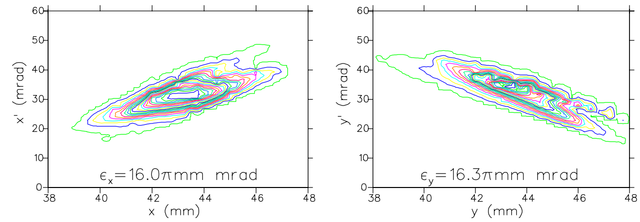

Figure 4: The measured transverse emittances of the $^{14}N^+$ commissioning beam.

7 mm radius. The fundamental frequency of 11.7 MHz and the first three harmonics are individually phase and amplitude controlled and combined at signal level. The signal is amplified by an 800 W broad-band amplifier that drives the two plates in push-pull mode with a peak voltage of about 200 V (400 V between plates). Optimization of amplitude and phase of each harmonic results in a saw-tooth modulation on the beam velocity. The variation in the gap-crossing efficiency for each harmonic means that the driving voltage is far from a sawtooth, being dominated by the higher, less efficient harmonics. In fact the present amplifier band width rolls off after 35 MHz and so initial testing was only done with three harmonics.

The pre-buncher was commissioned with a N^+ beam at 30 keV. The time structure of the bunched beam was measured on a 50Ω co-axial fast Faraday cup[6] with a resolution estimated at 0.5 nsec. Measured bunch structures for one, two and three harmonic bunching are shown in Fig. 5. The buncher was tuned by first setting the phase of each harmonic individually and then adjusting the voltage to pre-

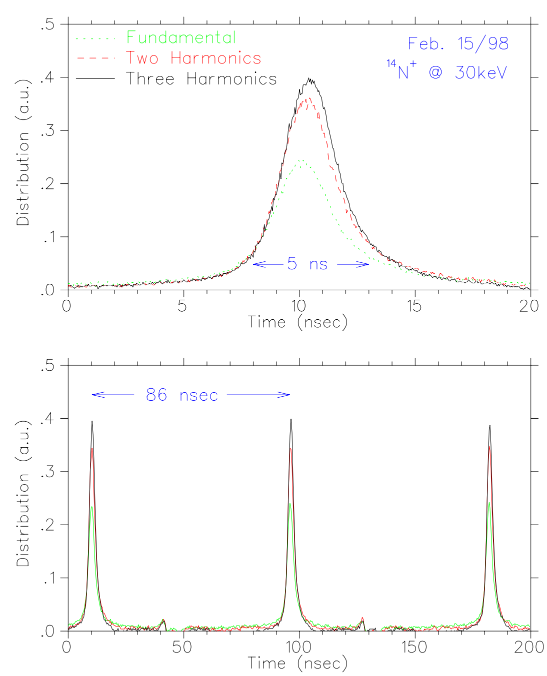

Figure 5: Beam bunches measured on the fast Faraday cup in LEBT for one, two or three harmonic bunching.

viously calculated values. The tuning was straightforward and the performance matches the predictions of simulation studies.

2.3 RFQ Preparation

RF signal level tests have been performed on the 7-ring volume using both unmodulated *dummy* electrodes and the final copper electrodes. The *dummy* electrodes were installed to get an early frequency measurement and to check the mechanical alignment of the electrodes. The results of the tests are a frequency of 35.7 MHz, a quality factor of $Q = 8700$, and a shunt impedance of 292 kΩ·m. The frequency will be slightly lower for the full 19 rings. Bead pull measurements show that the average peak field along the electrode length varies by no more than ±1% and that the asymmetry in the quadrupole field is less than ±1%. The electrodes themselves are aligned to the ideal beam axis to within the tolerance of $\pm 80\mu$.

In-Tank Beam Transport The beam from the RFQ is brought to a double waist after the first four quadrupoles and again at the exit of the RFQ. The characteristics of the beam at the exit of the RFQ electrodes are calculated using `PARMTEQ` corrected for the eight term potential. The quadrupoles are each 30 cm long with a 2.5 cm half aperture and require maximum voltages of just under 10 kV for $A = 30$. For mechanical reasons the RFQ vanes are orientated at 45° to the horizontal. As a consequence the first four electrostatic quadrupoles are also at 45°. The transverse reference frame is rotated to the normal after the first double waist where the beam is round. A wire scanner profile monitor and Faraday cup are located upstream of Q1, Q5 and at the tank exit.

2.4 Diagnostic Station

The diagnostic station is designed around a $\rho = 1.5$ m analyzing magnet with a dispersion of 3 cm/%. The magnet is placed symmetrically between horizontally defining object and image slits 1.5 m upstream and downstream of the magnet respectively. The last four quadrupoles in the RFQ are used to focus the beam through the object slit. A Faraday cup just downstream of the image slit records the transmitted beam and the energy and energy spread are derived from the magnetic field. A slit and harp transverse emittance rig and fast Faraday cup are located just upstream of the magnet.

3 BEAM TESTS

Beam tests are now underway. Initial results look very promising. The first beam (7.3μA of N^+, unbunched) was injected June 12/98. RF conditioning to achieve the required voltage of 35 kV at 100% duty cycle took only one day. Matching the beam to the RFQ and tuning the electrostatic quadrupoles in the RFQ proved to be straightforward. The acceleration efficiency as measured at the di-

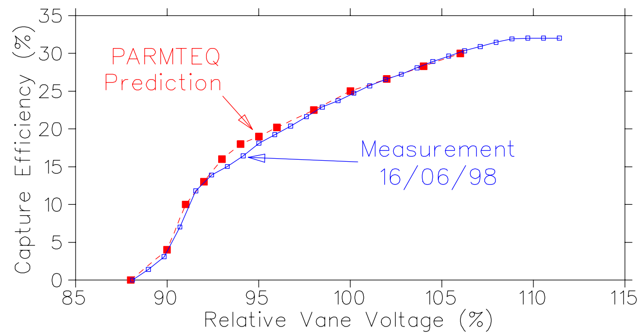

Figure 6: Initial beam test measurement with unbunched N^+ beam. Shown is the measured capture efficiency as a function of vane voltage and the corresponding prediction from PARMTEQ.

agnostic station is 25% at the nominal voltage and varies with vane voltage in the predicted way (Fig. 6). The energy and energy spread as measured with the analyzing magnet are 55 keV/u (0.77 MeV) and ±1% respectively. All values compare very well with predictions from `PARMTEQ` assuming an unbunched beam. (The beam energy is higher than originally quoted since the RFQ test frequency is 2% higher than the design frequency.) Preliminary beam tests with bunched beam give a capture efficiency of 50%, 60% and 70% for one, two and three harmonic bunching respectively. We eventually expect 76% for the latter case. The energy spread for the bunched beam was ±0.6% FWHM.

Tests will continue through the summer. Conditioning will proceed to full voltage and beam tests with both unbunched and bunched beams for a number of different ions will be completed. The primary goal is to demonstrate that the RFQ can be operated stably with the predicted transmission while producing beams with the predicted beam quality.[7]

4 REFERENCES

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