FIRST BEAM TEST WITH THE ISAC RFQ

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Abstract

The ISAC RFQ is a 35 MHz, split-ring, four vane structure designed to accelerate ions of $A/q \leq 30$ from 2 keV/u to 150 keV/u in cw mode. When completed the RFQ will comprise 19 split rings and modulated electrodes in quadrature for a total length of about 8 m. The first 7-ring portion of the RFQ is being tested with beam in an interim configuration. A copper wall internal to the RFQ tank isolates the rf power to the electrode region. Electrostatic quadrupoles are installed in the remainder of the tank to transport the beam to a downstream diagnostic station. An injector composed of an ion source and an electrostatic LEBT and matching section delivers stable light ions to the RFQ. The beam is pre-bunched with an 11.7 MHz pseudo saw-tooth waveform across a single gap. The diagnostic station consists of Faraday cups, a fast Faraday cup, an emittance rig, and an analyzing magnet. The complete test set-up will be described and the results of commissioning the injector and testing the RFQ will be presented.

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 $A/q \leq 30$ from 2 keV/u to 150 keV/u.

The ISAC RFQ (Fig. 1) is a split ring 4-rod structure[2]. A total of 19 split rings, each feeding a 40 cm length of modulated electrodes, are housed in a square 1m×1m tank with a total length of almost 8 m. The gross specifications include a bore radius of $r_0 = 7.4$ mm, and a maximum inter-vane voltage of 74 kV corresponding to a power of 85 kW. 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 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 RFQ but in addition, injecting a pre-bunched beam 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 that is useful for some physics experiments. We expect 81% of the beam to be accelerated in the 11.7 MHz bunches, ∼4% accelerated in the two neighbouring 35 MHz buckets, with 15% of the beam unaccelerated.

It was decided to proceed with a two-stage installation. We have installed the first seven rings of the RFQ for an interim beam test subsequent to installation of 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 RFQ completion in 1999.

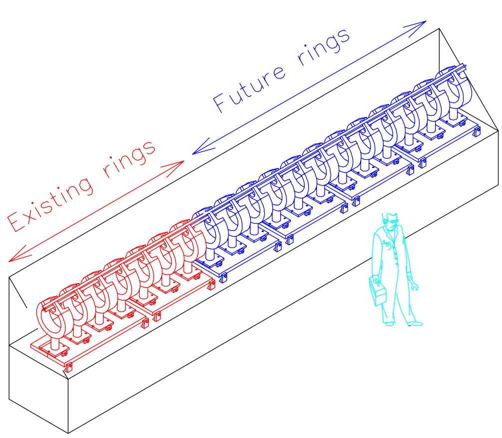

Figure 1: The ISAC 19 ring 35 MHz RFQ.

2 THE TEST SET-UP

A schematic of the test set-up is shown in Fig. 2. A copper wall installed downstream of the seven ring section provides rf containment. 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 accelerated

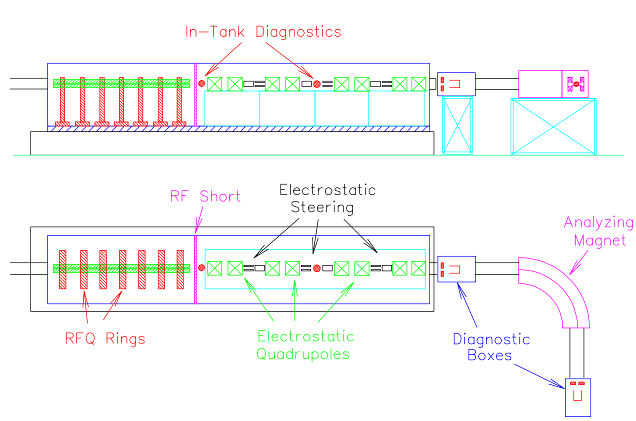

Figure 2: A schematic view of the RFQ and test station.

to 53 keV/u, then a series of eight electrostatic quadrupoles transports the beam to a diagnostic station just downstream of the RFQ tank.

2.1 OLIS and LEBT

A schematic of the ion source (OLIS) and injection line (LEBT) are shown in Fig. 3. 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. The LEBT consists of electrostatic elements; quadrupoles, steerers and spherical bends[4]. The source efficiently produces positive ions of gaseous species from Hydrogen to Argon. The ions for the initial RFQ tests are $^{14}N^{+}$ and $^{28}N_2^{+}$ with transverse emittances measured to be $20\pi\mu$m and $10\pi\mu$m respectively.

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 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 an almost 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 done with only three harmonics.

The time structure of the bunched beam as measured

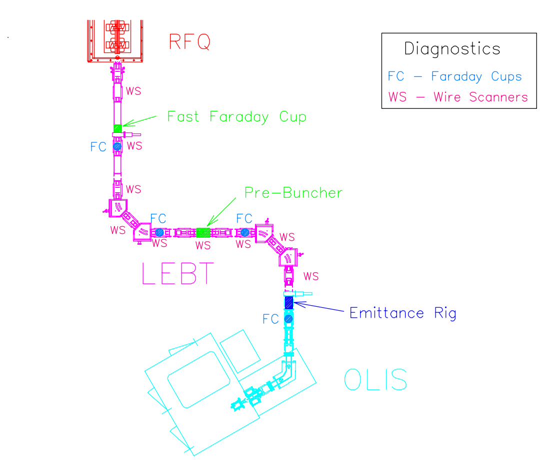

Figure 3: The layout of the off-line ion source (OLIS) and low energy beam transport (LEBT) upstream of the RFQ. The commissioning diagnostics are indicated.

on a 50Ω co-axial fast Faraday cup[5] for one, two and three harmonic bunching are shown in Fig. 4. The buncher was tuned by setting the phase of each harmonic individually, then adjusting the voltage to previously calculated values followed by empirical optimization. The tuning was straightforward and the performance matches the predictions of simulation studies.

2.3 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 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.

2.4 Diagnostic Station

The diagnostic station is designed around a $\rho = 1.5$ m analyzing magnet with a dispersion of 3 cm/%. [1] The magnet is placed symmetrically between horizontally defining object and image slits 1.5 m upstream and downstream of the magnet respectively. A Faraday cup upstream of the object slit measures the final beam intensity and when compared with the last Faraday cup in LEBT gives the relative beam capture. Unaccelerated beam is lost in the electrostatic quadrupoles. 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 have recently been placed upstream of the magnet.

3 RFQ BEAM TESTS

The initial set of rf and beam tests have been successfully completed. The RFQ was operated in cw mode for all beam tests. The operation of the RFQ at peak voltage (74 kV) is

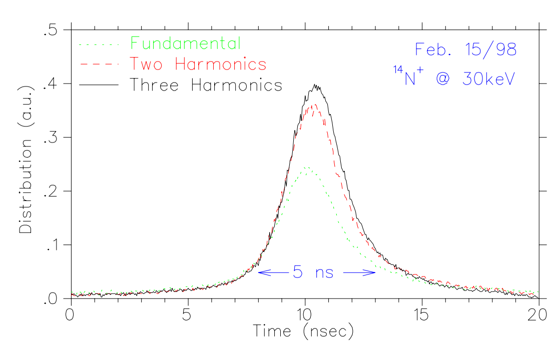

Figure 4: Beam bunches measured on the fast Faraday cup in LEBT for one, two or three harmonic bunching.

[1] The magnet was generously donated by the Nuclear Physics Institute in Rez, Czech Republic.

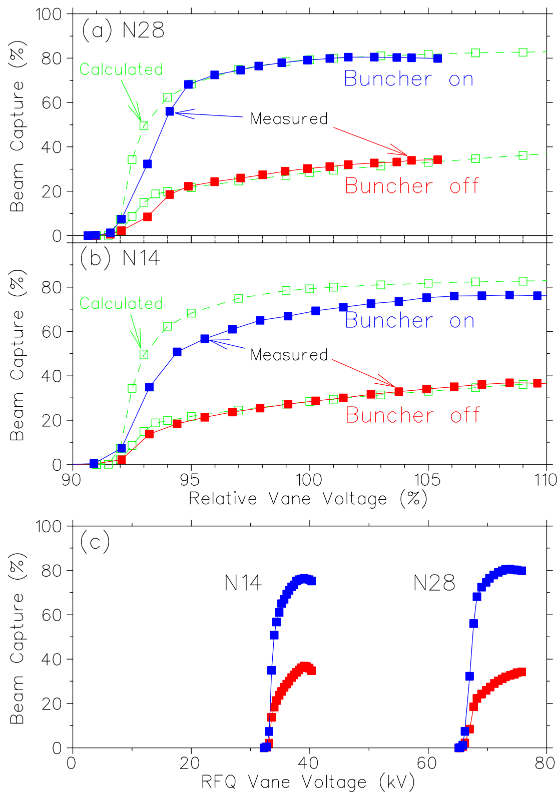

Figure 5: RFQ beam test results showing capture efficiency as a function of relative vane voltage for (a) N_2^+ and (b) N^+. The nominal vane voltage in each case was 71.9kV and 36 kV respectively. The beam capture for both bunched and unbunched initial beams are recorded (solid line) and are compared with PARMTEQ calculations (dashed lines). In (c) the results are plotted with respect to absolute vane voltage.

stable[2]. Beams of both N^+ and N_2^+ have been accelerated to test the RFQ at both low and high power operation.

Beam capture as a function of RFQ vane voltage measurements have been completed for each ion and for both unbunched and bunched input beams. The results are given in Fig. 5 (solid lines) along with predicted efficiencies based on `PARMTEQ` calculations (dashed lines). The N_2^+ capture efficiency at the nominal voltage is 80% in the bunched case (three harmonics) and 30% for the unbunched case in agreement with predictions. (The capture is lower than the 85% quoted earlier since we are presently operating with only three harmonics on the pre-buncher.) The capture for one harmonic and two harmonic pre-bunching are 63% and 74% respectively. The results for N^+ are somewhat lower in the bunched case (70%) due, we think, to the larger transverse emittance reducing the bunching efficiency. In theory the LEBT and RFQ have an acceptance of eight times the measured emittance of N^+ so this result may be significant. However it may also be the result of a poor LEBT tune generating a non-achromatic condition in the electrostatic bend. It warrents further investigation.

The energy of the beam as measured with the analyzing

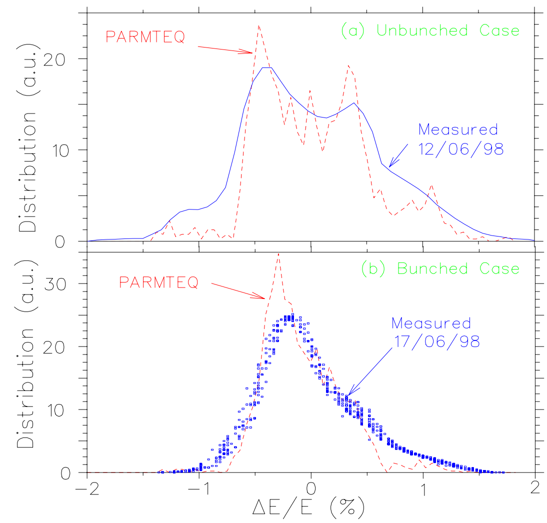

Figure 6: Results of energy spread measurements of accelerated N^+ beams for both (a) unbunched and (b) bunched cases. `PARMTEQ` simulation results are plotted for comparison.

magnet is 55 keV/u. The beam energy is higher than originally quoted since the RFQ test frequency is 2% higher than the design frequency. (The actual frequency is expected to drop with the addition of the remaining 12 rings.) The energy spread for the bunched and unbunched cases were measured at $\pm 0.4\%$ and $\pm 0.7\%$ respectively and compare well with `PARMTEQ` predictions (Fig. 6).

The results demonstrate a strong confirmation of both the beam dynamics design and the engineering concept and realization. We are presently installing diagnostics for a further set of tests [6] including measurements of longitudinal and transverse emittance and acceptance. These measurements will proceed through October 98 before we commence with the installation of the rest of the rings. Commissioning of the RFQ in the final configuration is expected in Fall 99.

4 REFERENCES

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