FIRST BEAM TEST WITH THE ISAC SEPARATED FUNCTION DTL

R.E. Laxdal, P. Bricault, G. Dutto, K. Fong, G.H. Mackenzie, R. Poirier, W. Rawnsley, R. Ruegg, G. Stinson, TRIUMF, Vancouver, Canada

Abstract

The ISAC Separated Function DTL is designed to accelerate ions of $3 \leq A/q \leq 6$ to energies fully variable between 0.153 to 1.53 MeV/u. The DTL includes five IH-tanks with quadrupole triplets between tanks and triple gap split ring bunchers before tanks 2, 3, and 4. The final configuration of the DTL is due for commissioning in Dec. 2000. Recently a beam test with the first section of the DTL comprising the first tank, a triplet and the first buncher has been completed. The experimental set-up and the test results are reported.

1 INTRODUCTION

The post-accelerator for the ISAC radioactive ion beam facility[1] includes a 11.8 MHz multi-harmonic pre-buncher, a 35.4 MHz RFQ to accelerate beams of $A/q \leq 30$ from 2 keV/u to 153 keV/u and a post-stripper, 106.1 MHz variable energy drift tube linac (DTL) to accelerate ions of $3 \leq A/q \leq 6$ to a final energy from 0.15 to 1.53 MeV/u. The RFQ has been fully commissioned[2]. The DTL is being installed [3] for final commissioning of the linac chain in Dec. 2000.

The DTL structure has been configured as a *separated function* DTL [4]. Five independently phased IH tanks operating at $\phi_s = 0°$ provide the main acceleration. Longitudinal focussing is provided by independently phased, triple gap, split-ring resonator structures positioned before the second, third and fourth IH tanks. Quadrupole triplets placed after each IH tank maintain transverse focussing. To achieve a reduced final energy, the higher energy IH tanks are turned off starting at the downsteam end and the voltage and phase in the last operating tank is varied. This unique configuration offers an efficient room-temperature approach to a variable energy cw heavy ion linac. A schematic drawing of the DTL is shown in Fig. 1.

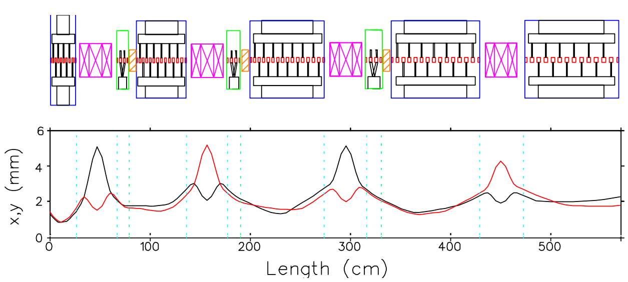

Figure 1: Schematic drawing of the ISAC variable energy 106 MHz DTL (upper figure) and corresponding beam envelopes (lower figure). The beam envelopes define the x and y maximum half sizes of the beam as a function of linac length. The calculations are for matched elliptical emittances of 0.25π μm (normalized).

Prior to construction it was decided to proceed with a two-stage installation. The first complete sub-section of the DTL consisting of the first IH tank, Tank1, plus a quadrupole triplet, Triplet1, and triple gap buncher, Buncher1, has been installed and tested with beam and is being followed by the installation of the remaining four sub-systems. The test allows us to perform rf conditioning *in situ*, debug rf controls, establish alignment procedures, commission the injection line and triplet, determine matching conditions and measure beam quality all well in advance of the final installation.

2 BEAM DYNAMICS

At full voltage the beam dynamics are typical of a 0° accelerating structure[5]; matched beams enter each accelerating section converging in all dimensions and after acceleration the now diverging beams are refocussed before the next accelerating section (Fig. 1).

At a reduced tank voltage the particle bunch is phased negatively with respect to the synchronous phase so that as the particles lose step with the synchronous particle and drift to more positive phases they gain the required energy. The upstream buncher is used to match the beam to the detuned tank. The buncher following the tank is then used to capture the diverging beam. In Fig. 2 we show the initial and final position of a grid of particles in longitudinal phase space after simulated acceleration in Tank1 for two different relative tank voltages, $V/V_o = 0.4$ and 0.8. Distortion of phase space occurs for phases near 0°. Below this the energy gain falls off nearly linearly with phase.

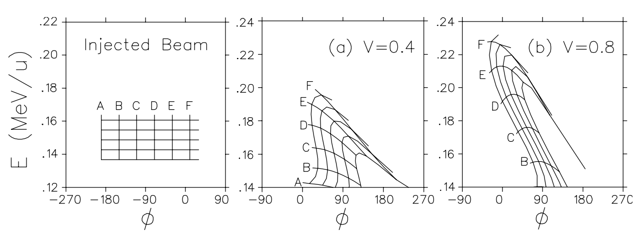

Figure 2: Final position in $E-\phi$ space of an initial grid of particles after acceleration through Tank1 for relative voltages of 0.4 and 0.8 with respect to the full energy case.

3 TEST SET-UP

A schematic of the test set-up is shown in Fig. 3. The medium energy beam transport (MEBT) transports the beam between RFQ and DTL. The MEBT consists of a matching section for the stripping foil, a charge selection section and a final matching section before the DTL. This matching section includes a 35.4 MHz spiral buncher and

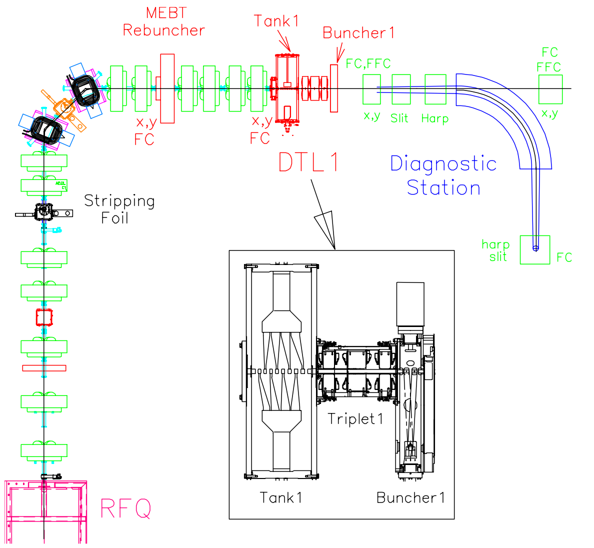

Figure 3: A schematic view of the MEBT, DTL1 and test station.

four quadrupoles. Narrow diagnostic boxes upstream of both the MEBT rebuncher and DTL-Tank1 each house a profile monitor (x,y) and Faraday cup (FC).

Tank1 consists of 9 cells covering a velocity range from $0.018c$ to $0.022c$, with a maximum effective voltage of 0.5 MV yielding a maximum final energy of 0.24 MeV/u for $A/q = 6$ and a length of 26 cm. Each triplet consists of quadrupoles with effective lengths of 5.8, 8.7 and 5.8 cm with maximum gradients of 6.7, 7.5, 6.7 T/m and a total length of 37.5 cm. Horizontal and vertical steering coils are wound in the central quadrupole. The first split ring buncher[6] has a design velocity of $0.023c$, a maximum effective voltage of 0.19 MV and a length of 10 cm.

The diagnostic station downstream of the Tank1, Triplet1 and DTL-Buncher1 includes Faraday cups (FC) for beam transmission measurements, a slit and harp transverse emittance rig, two 50Ω co-axial fast Faraday cups (FFC) for pulse width and TOF measurements and a 90° bending magnet with a dispersion of 3 cm/%($\frac{\Delta p}{p}$) to analyze the energy and energy spread in the beam.

4 BEAM TESTS

Test results reported here are for unstripped beams of $^{4}He^{1+}$ (300 nA) and beams of $^{14}N^{4+}$ (100 nA) stripped with a $3-5$ μgm carbon foil. These ions require moderate DTL voltages. In a separate test the successful acceleration of $^{14}N^{2+}$ proves operation at high power ($A/q = 7$). In all cases 100% transmission is achieved.

The transverse emittances injected into the DTL are typically 0.06 $\pi\mu$m. The longitudinal emittance is measured by varying the MEBT rebuncher while measuring beam energy spread and pulse width and gives a longitudinal emittance (95% included) of 0.6π keV/u-ns for the unstripped beam and about two to three times this for the stripped beam. Long term stability of a tune was hampered by foil aging; carbon build up on the foils caused a gradual reduction of beam energy and thus drift in the beam phase. Typical beam intensities of 100 nA of Nitrogen resulted in foil lifetimes of $1-2$ hours.

4.1 *Energy Variation*

Beam energy and pulse width measurements for various Tank1 voltage and phase values (Buncher1 off) confirm that variable energy operation works as predicted. Measured energy spectra for a relative tank voltage of 72% and at various rf phase set-points are given in Fig. 4(a). For each setting the MEBT rebuncher voltage was optimized to produce the best longitudinal beam quality. In general there are a broad range of voltage settings available to achieve a given energy, while still maintaining acceptable longitudinal beam characteristics. For a fixed energy a lower Tank1 voltage (more positive phase) requires a stronger MEBT rebuncher setting for best beam quality. Measured Tank1 voltage and phase values to achieve a given energy are plotted as solid contours in Fig. 4(b) and compared to simulation results (dashed lines through large open squares). Agreement is good except at the high voltage/low phase regime where some discrepancy exists that requires further investigation.

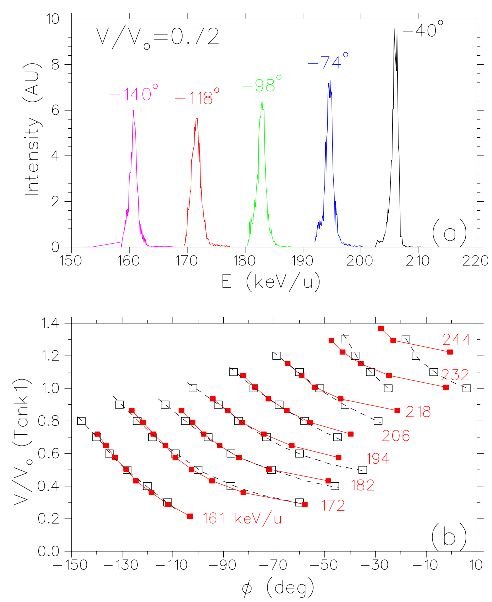

Figure 4: In (a) the Tank1 voltage setting is fixed to $V/V_o = 0.72$ and the phase altered to produce various energy spectra for $^{4}He^{1+}$. In (b) a summary plot shows the resultant final energy contours as a function of Tank1 voltage and phase; the small squares (solid lines) correspond to measured values and the large squares (dashed lines) correspond to simulated values.

4.2 *Longitudinal Emittance*

Longitudinal emittance measurements of the accelerated beam are done by varying the Buncher1 voltage and measuring the energy and time spectra at an energy spread minumum. Sample spectra are given in Fig. 5 for the $^{4}He^{1+}$ beam. These spectra give emittance values of $0.5 - 0.6\pi$keV/u-ns consistent with little or no longitudinal emittance growth over the whole energy range.

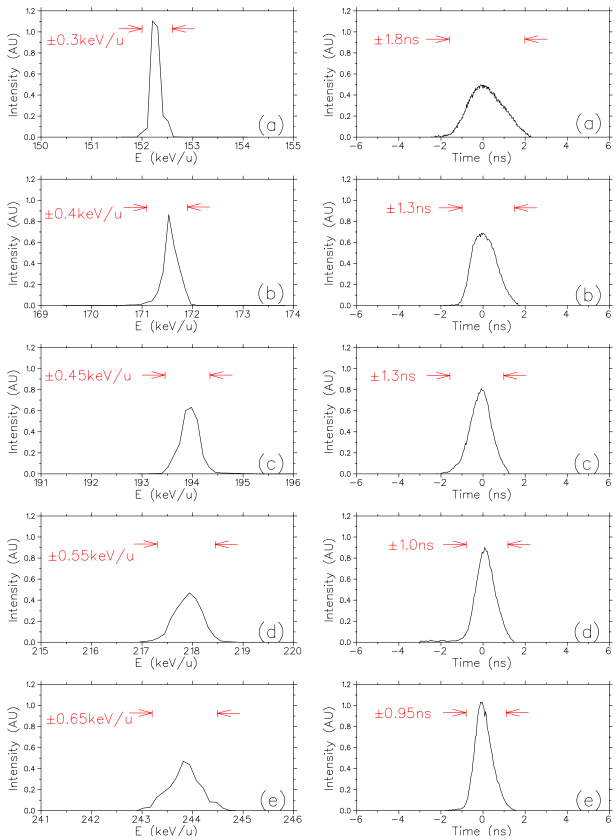

Figure 5: Beam results giving final energy spectra and pulse width for five sample energies covering the full accelerating range of the first DTL subsection.

4.3 *Transverse Emittance*

Transverse emittance measurements for the $^{14}N^{4+}$ beam are summarized in Fig. 6. Shown are phase space densities and computed normalized emittances (4RMS values) before the RFQ, after RFQ acceleration and stripping, after rebunching in MEBT, after acceleration to full energy in Tank1 and finally after rebunching in Buncher1. The largest emittance increase occurs in the stripping foil with only a small increase during acceleration. This could be improved after the planned installation of another profile diagnostic downstream of Buncher1 to further control beam size during acceleration. Emittance measurements at two lower energies, 200 keV/u and 215 keV/u give final transverse emittances consistent with those at 230 keV/u.

5 CONCLUSION

The beam test demonstrates the versatility of the separated function concept. New tunes can be established in a short time and the measured beam quality matches predictions of beam simulations. As well the test helped to identify

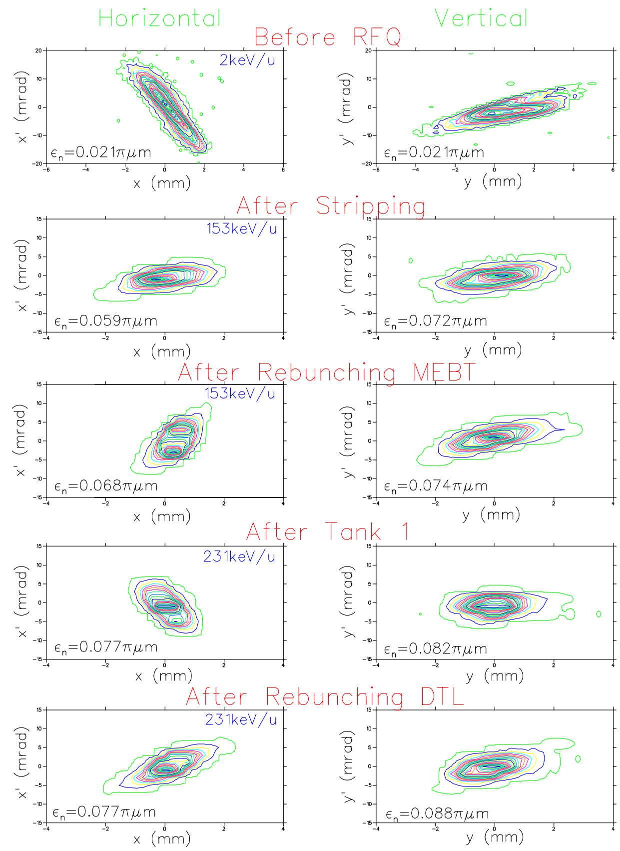

Figure 6: Transverse emiitance measuremetns after various stages in beam test.

potential future problems. Initial difficulties with phase-locking all rf devices due to the limited RFQ tuner range and microphonics in Buncher1 were eventually overcome. We have identified foil thickening as responsible for beam phase shifts in the DTL. It is planned to reduce the build-up by cleaning the section, adding a cold trap around the stripping foil and by providing a beam feedback signal to a bias voltage on the stripping foil to correct the energy loss.

6 REFERENCES

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