STATUS OF THE ISAC ACCELERATOR FOR RADIOACTIVE BEAMS

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Abstract

The ISAC radioactive beam facility under construction at TRIUMF includes a 500 MeV proton beam ($I \leq 100\ \mu$A) impinging on a thick target, an on-line source, a mass-separator, an accelerator complex, and experimental areas. The accelerator chain includes a 35 MHz RF Quadrupole (RFQ) to accelerate beams of $A/q \leq 30$ from 2 keV/u to 150 keV/u and a post-stripper, 105 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 1.5 MeV/u. The present status of the accelerator complex will be summarized. In particular, first rf and beam tests with the RFQ and the fabrication status of the DTL will be reported.

1 INTRODUCTION

A radioactive ion beam facility with on-line source and linear post-accelerator is being built at TRIUMF[1]. [1] In brief, the facility includes a proton beam (I$\leq$100$\,\mu$A) from the TRIUMF cyclotron impinging on a thick target, an on-line source to ionize the radioactive products, a mass-separator for mass selection, an accelerator complex and experimental areas. Beams of $E \leq 60$ keV and $A \leq 238$ will be delivered to the low energy experimental area. The accelerator chain includes a 35 MHz RFQ to accelerate beams of $A/q \leq 30$ from 2 keV/u to 150 keV/u and a post stripper, 105 MHz variable energy drift tube linac (DTL) to accelerate ions of $3 \leq A/q \leq 6$ to a final energy between 0.15 MeV/u to 1.5 MeV/u. The accelerators have several noteworthy features. Both linacs are required to operate cw to preserve beam intensity. The RFQ, a four vane split-ring structure, has no bunching section; instead the beam is pre-bunched at 11.7 MHz with a single-gap, pseudo saw-tooth buncher. The variable energy DTL is based on a unique separated function approach with five independent interdigital H-mode (IH) structures providing the acceleration and quadrupole triplets and three-gap bunching cavities between tanks providing transverse and longitudinal focussing respectively. A layout of the ISAC accelerator chain is shown in Fig. 1.

During 1998 TRIUMF management shifted the priority in ISAC to the target hall and mass-separator areas. Consequently progress on the accelerator has slowed somewhat. Nonetheless the building is complete and occupancy of the accelerator floor began in July 1997. In less than a year a source and injection line have been commissioned and initial rf and beam tests with the RFQ in an intermediate configuration have been successfully completed. In addition the first DTL buncher has been delivered in preparation for rf tests and the first DTL IH tank is ready for copper plating.

[1] http://www.triumf.ca/isac/lothar/isac.html

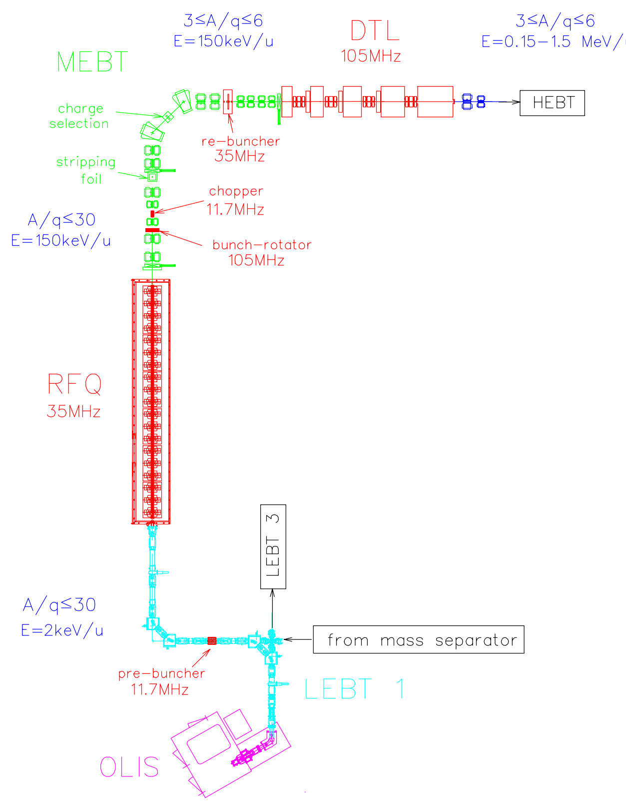

Figure 1: The ISAC linear accelerator.

2 LEBT

The low energy beam transport (LEBT) consists of electrostatic elements; quadrupoles, steering plates and spherical bends, that transport the exotic beams from the mass-separator and stable beams from an off-line ion source (OLIS) located on the accelerator floor[2]. An electrostatic switchyard allows selection of either the stable or unstable beam for acceleration while the other beam can be sent to the low energy experimental area.

The beam to be accelerated is pre-bunched at 11.7 MHz, the third sub-harmonic of the RFQ frequency, in a single gap, multi-harmonic pseudo-sawtooth pre-buncher. The pre-buncher frequency was selected at the request of experimenters to give a longer bunch spacing (86 ns), a useful feature for certain TOF and coincidence rejection techniques.

The pre-buncher is positioned ∼5 m upstream of the RFQ. The last four quadrupoles upstream of the RFQ match the beam to the RFQ acceptance.

Installation of the off-line ion source (OLIS) began in July 97 with first beam extracted in November 97. Commissioning of the LEBT from OLIS to the RFQ followed soon after. The saw-tooth prebuncher was installed and commissioned with three harmonics in February 98. The fourth harmonic will be added following an upgrade to the wide band amplifier. During commissioning the bunched beam structure was measured with a cone type fast Faraday cup. Tuning proved relatively straight forward, the phase of each harmonic was determined with the beam and the amplitudes were set to pre-determined values followed by empirical optimization.

3 RFQ

The 8 m long, 1m×1m ISAC RFQ tank (Fig. 2) houses 19 split ring structures each feeding 40 cm lengths of modulated electrode. Both rings and electrodes are water cooled to dissipate the expected 100 kW of rf power[3]. The design peak voltage between electrodes is 74 kV, with a bore radius of r_0=7.4 mm.

The buncher and shaper sections of the RFQ have been completely eliminated from the design in favour of a four-harmonic sawtooth pre-buncher[4]. This not only has the benefit of shortening the structure but also reduces the output longitudinal emittance. These gains are made at the expense of a slightly lower beam capture. We expect 81% of the beam will be accelerated in the 11.7 MHz buckets while ∼3.5% will be accelerated in the two 35 MHz side-buckets with ∼15% of the beam unaccelerated and lost in the MEBT.

The initial seven ring segment of the RFQ (2.8 m) has been installed for an interim rf and beam test[5]. A copper wall is located just downstream of the seven ring section to isolate the rf fields. The beam is accelerated to 55 keV/u and then eight electrostatic quadrupoles, located inside the RFQ tank, transport the beam to a diagnostic station located at the exit of the RFQ. Signal level measurements of the rf have determined a frequency of 35.7 MHz, a shunt impedance of 292 kΩ·m and $Q = 8700$. Power level tests have confirmed stable operation in cw mode at peak voltage[3]. First beam was accelerated June 6/98. Since then both N^+ ($A = 14$) and N_2^+ ($A = 28$) have been accelerated testing performance at both low and high power with excellent results. In particular, in the case of N_2^+, 80% of the beam was accelerated with three harmonics on the pre-buncher in perfect agreement with PARMTEQ predictions (Fig.3). The beam quality also is as expected. The tests will continue through October 98. The remainder of the rings will then be installed with the commissioning of the full RFQ in the fall of 1999.

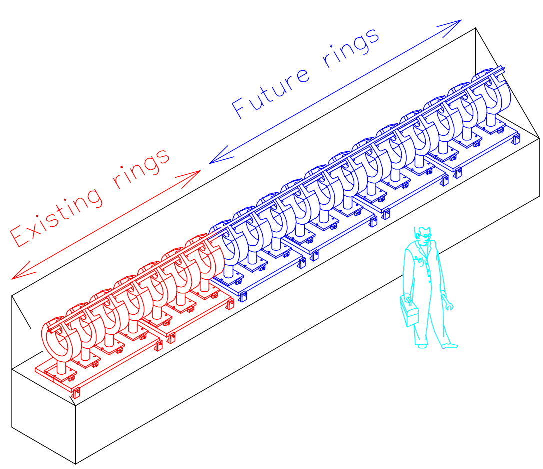

Figure 2: The ISAC 35 MHz RFQ.

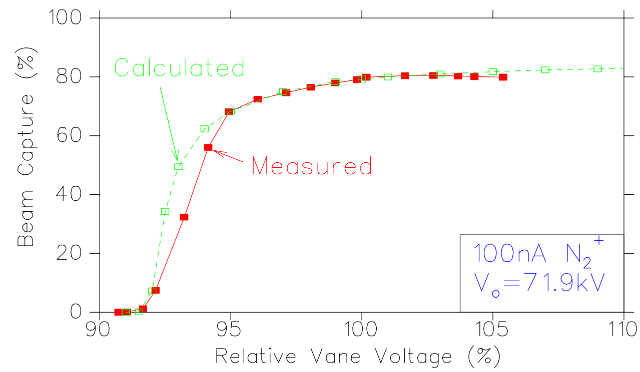

Figure 3: Beam test results from the RFQ. Shown is the capture efficiency of a N_2^+ beam as a function of relative vane voltage (solid line). The calculated capture efficiency is plotted (dashed line) for comparison.

4 MEBT

The beam is stripped in the medium energy beam transport (MEBT) with a thin carbon foil ($3\ \mu$gm/cm^2) to boost the charge state before acceleration in the DTL. The beam from the RFQ is focussed in three dimensions onto the stripping foil with quadrupoles and a 105 MHz double gap bunch rotator to minimize emittance growth due to multiple scattering and energy straggling. A chopper eliminates the small quantity of beam (∼3%) accelerated in the two 35 MHz buckets neighbouring the main pulse. After charge selection the beam is matched into the DTL with quadrupoles and a 35 MHz re-buncher.

All quadrupoles have been received. A two-gap spiral re-buncher is presently in development. A model has been completed to study the mechanical rigidity. The MEBT will be installed in the summer of 1999 in time to commission the full energy RFQ.

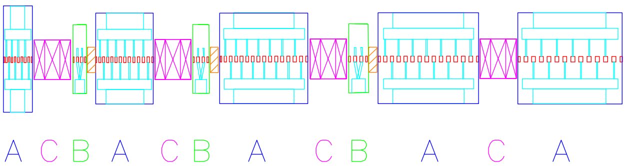

Figure 4: Schematic drawing of the ISAC variable energy separated function DTL. Five IH tanks (A) provide acceleration at 0° synchronous phase, three triple gap spiral resonators (B) provide longitudinal focus ($\phi_s \sim -60°$) and quadrupole triplets (C) provide transverse focus.

5 DRIFT TUBE LINAC

A schematic drawing of the DTL is shown in Fig. 4. The separated function design [6] offers the flexibility and beam quality of a super-conducting linac but at a reduced cost and complexity. To achieve a reduced final energy the higher energy IH tanks are turned off and the voltage and phase in the last operating tank are varied. The three-gap split ring cavities are adjusted to maintain longitudinal bunching. In this way the whole energy range can be covered with 100% transmission and no longitudinal emittance growth.

Fabrication of the first IH tank and the first split-ring buncher are proceeding in advance of the bulk of the DTL in order to get experience with the fabrication techniques. The stems and ridges of the first tank have been received. They are both fabricated from solid copper. The completed tank is being copper plated prior to final assembly. Power tests are scheduled for the fall.

The first DTL buncher[7], a split-ring three gap structure operating at 105 MHz, has been designed and fabricated at INR-RAS Troitsk and has been delivered to TRIUMF for power level tests. The fabrication of the remainder of the cavities will proceed after the acceptance tests are complete. The quadrupole triplets have been specified and are presently in design. Commissioning of the DTL is expected in the middle of 2000.

6 BEAM QUALITY

The beam from the source is expected to have a transverse emittance no larger than $\epsilon_{x,y} = 50\pi\mu$m corresponding at 2 keV/u to a normalized emittance of $\epsilon_n = \beta\gamma\epsilon = 0.1\pi\mu$m. The expected transverse and longitudinal emittances at various locations in the accelerator chain are shown in Table 6. The values quoted enclose 98% of the particles. Note the effect of multiple scattering and energy straggling in the stripping foil and the small emittance growth in the MEBT rebuncher. The transverse acceptance of the RFQ and DTL are large enough that no emittance increase is expected during acceleration. The technique of pre-bunching the beam entering the RFQ and eliminating the bunching and shaping section in the RFQ gives a very compact beam in longitudinal phase space. The longitudinal acceptance of the DTL and flexibility of the design are such that not more than 10% emittance growth is expected over the whole energy range.

Table 1: Simulation results showing the beam emittance at various locations in the ISAC accelerator chain. The values quoted enclose 98% of the particles.

Position	Transverse		Longitudinal	
	$\epsilon_{x,y}$	$\beta\epsilon_{x,y}$	ϵ_z	ϵ_z
	($\pi\mu$m)	($\pi\mu$m)	(π% ns)	(πkeV/u ns)
LEBT	50	0.1	DC	DC
After RFQ	5	0.1	0.33	0.5
After Foil	10	0.2	0.45	0.67
Before DTL	11	0.22	0.50	0.74
After DTL	$11\cdot(\frac{0.018}{\beta_{fin}})$	0.22	$0.5\cdot(\frac{0.15}{E_{fin}})$	0.74

7 FUTURE PLANS - ISAC2

TRIUMF is currently preparing a new five year plan requesting additional funding from the Canadian Government for the period beginning in April 2000. A major element of this plan includes an upgrade of the ISAC facility, ISAC2, to permit acceleration of radio-active ion beams up to energies of at least 6.5 MeV/u for masses up to 150[8]. In brief the proposed acceleration scheme would use the existing RFQ with the addition of an ECR charge state booster to achieve the required charge to mass ratio ($q/A \geq 1/30$) for masses up to 150. A new room temperature drift tube linac would accelerate the beam from the RFQ to 400 keV/u where the beam could be more efficiently stripped to give a charge to mass ratio greater than 1/7 for the full mass range. This beam would then be accelerated by a linac consisting of many short superconducting cavities. The design is compatible with staging scenarios that achieve beams up to ~5 MeV/u and A up to 60 as early as 2003 albeit with reduced ion intensity compared to the completed facility.

8 REFERENCES

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