

ISAC AT TRIUMF: RECENT ACHIEVEMENTS AND FUTURE GOALS

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Abstract

The ISAC facility at TRIUMF is now routinely delivering record intensities of radioactive ions to low energy experiments ($E \leq 60$ keV). The post-accelerator for ISAC includes a 35.4 MHz RF Quadrupole (RFQ) and a post-stripper, 106.1 MHz variable energy drift tube linac (DTL) to accelerate ions to a final energy from 0.15 to 1.5 MeV/u. The RFQ has been fully commissioned and the DTL is being installed for final commissioning of the linac chain in Dec. 2000. Recently funds have been allocated for an extension to the ISAC facility, ISAC-II, to permit acceleration of radio-active ion beams up to energies of at least 6.5 MeV/u for masses up to 150. The present status of both the ISAC-I accelerator and the future ISAC-II project are presented below.

1 INTRODUCTION

The first stage of a radioactive ion beam facility at TRIUMF, ISAC-I[1], is nearing completion. In brief, the facility includes a 500 MeV proton beam ($I \leq 100 \mu\text{A}$) 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. Present licensing permits continuous operation at $10 \mu\text{A}$ proton intensity with limited operation at $20 \mu\text{A}$. Beams of $E \leq 60$ keV and $A \leq 238$ are being delivered to the low energy experimental area. Recent beams delivered to experiments are 2×10^7 pps $^{38\text{m}}\text{K}$ and 4×10^3 pps ^{74}Rb .

The accelerator chain includes a 35.4 MHz RFQ, now fully commissioned [2], to accelerate beams of $A/q \leq 30$ from 2 keV/u to 153 keV/u and a post stripper, 106 MHz variable energy drift tube linac (DTL), presently being installed [3] to accelerate ions of $3 \leq A/q \leq 6$ to a final energy between 0.153 MeV/u to 1.53 MeV/u. A low energy beam transport (LEBT) delivers stable beams from the off-line source (OLIS) or exotic beams from the mass-separator to the RFQ. The LEBT houses an 11.8 MHz multi-harmonic pre-buncher 5.7 m upstream of the RFQ. The medium energy beam transport (MEBT) is composed of a matching section to the stripping foil, a charge selection section and a matching section to the DTL. A two frequency chopper cleans up the time structure and a 106 MHz bunch rotator produces a time focus on the stripper. The DTL matching section utilizes a 35.4 MHz spiral rebuncher. The high energy beam transport (HEBT) delivers the beam from the DTL to the experimental stations. A bunching station consisting of a low- β 11.8 MHz triple gap structure and a high- β 35.4 MHz spiral resonator are incorporated to maintain the good longitudinal emittance to the

target. All rf devices operate *cw* to preserve beam intensity. A layout of the post-accelerator for ISAC is shown in Fig. 1.

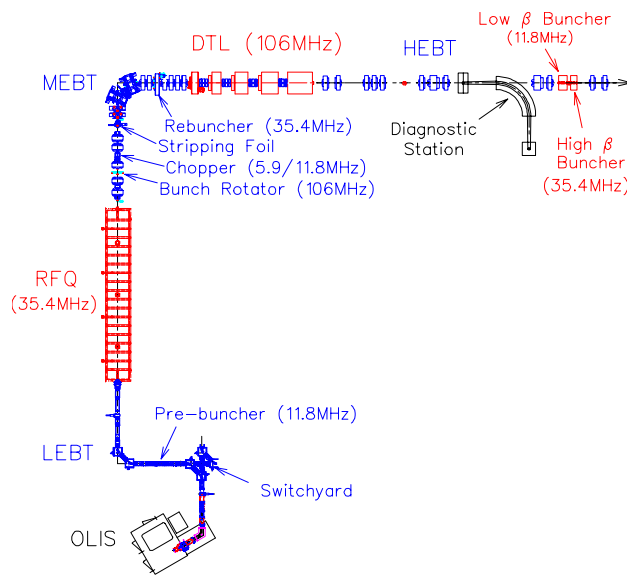


Figure 1: Schematic drawing of the ISAC-I experimental hall.

Recently funds have been allocated for an extension to the ISAC facility, ISAC-II, to permit acceleration of radioactive ion beams up to energies of at least 6.5 MeV/u for masses up to 150. The proposed acceleration scheme would use the existing RFQ with the addition of an ECR charge state booster to achieve the required mass to charge ratio ($A/q \leq 30$) for masses up to 150. A new room temperature IH-DTL would accelerate the beam from the RFQ to a new stripping energy of 400 keV/u followed by a superconducting linac designed to accelerate ions of $A/q \leq 7$ to the final energy. A schematic of the proposed ISAC-II linear accelerator complex is shown in Fig. 2.

2 ISAC-I STATUS

2.1 LEBT

OLIS and LEBT including the multi-harmonic pre-buncher have been operational since 1998. The pre-buncher operates at a fundamental frequency of 11.8 MHz, the third sub-harmonic of the RFQ. This introduces an 85 nsec bunch spacing that is useful for experiments. Presently three frequencies are utilized in the pre-buncher giving an over-all efficiency of 75% capture in the 11.8 MHz pulses with 5% of the beam in the two 35.4 MHz side-bands. (The measured beam time structure after acceleration to 230 keV/u

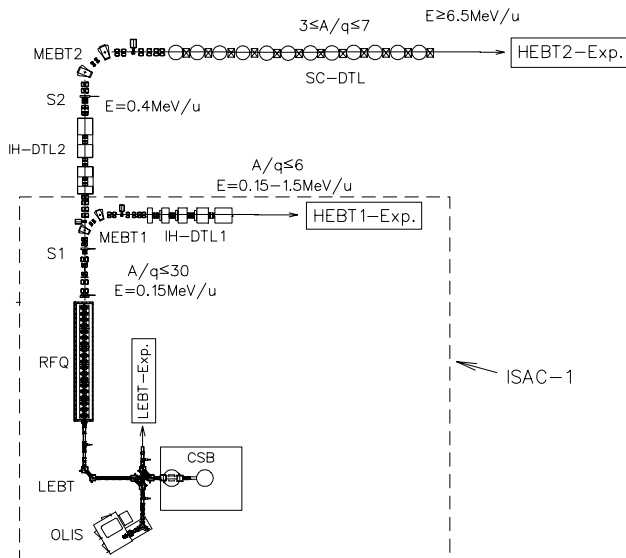


Figure 2: The proposed ISAC-II post-accelerator.

in the first DTL section is shown in Fig. 3(a). Simulations show that the addition of a fourth harmonic component would increase the capture to $\sim 80\%$. A new wide-band amplifier is being planned for this purpose.

2.2 RFQ

The ISAC RFQ is a split ring 4-rod structure, 8 m in length operating up to an inter-vane voltage of 74 kV and power of 85 kW[2]. A unique feature of the design is the constant synchronous phase of -25° . Since in radioactive beam acceleration space-charge is not a concern we have eliminated the buncher and shaper sections in favour of the pre-buncher. 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 RFQ has now been fully commissioned. In one acceptance test the rf was operated at full power for 100 hours. Full energy beam tests in Feb. 2000 and June 2000 confirmed beam dynamics calculations. In particular the design choices taken to reduce the longitudinal emittance proved successful with a measured value of $0.5 \pi \text{keV/u-ns}$ in agreement with calculations. In addition the measured beam capture of 80% (75% for the 11.8 MHz bunch) compares well to beam simulations.

2.3 MEHT

The MEHT optics and 35.4 MHz rebuncher have been fully commissioned with beam and in most cases operation is as expected. However foil aging has been identified as an area that requires further study. A contamination of oil in the foil box deposits carbon on the foil during beam heating, thickening the foil and gradually shifting the beam energy. The plan is to clean the beamline, add a cold trap around the foil and stabilize the post-stripper beam energy by biasing the foil through a beam feedback signal.

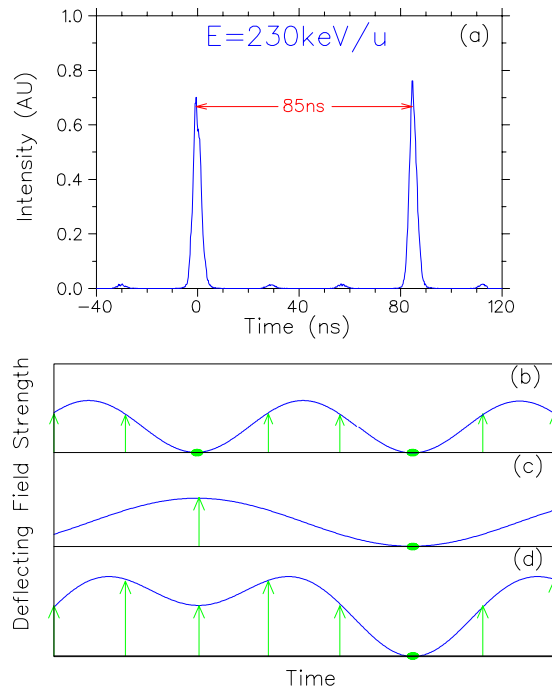


Figure 3: (a) Output time structure of $^{14}\text{N}^{4+}$ beam after acceleration to 230 keV/u with RFQ and DTL1. The field produced by the 11.8 MHz chopper plate (b) for a 85 ns time structure and the field produced by the 5.9 MHz plate (c) are combined in (d) to show the deflecting strength for the 170 ns time structure.

A bunch rotator and chopper are presently being readied for installation upstream of the stripping foil. The 106 MHz split ring bunch rotator is the slightly modified prototype buncher for the DTL[4]. It is designed to provide a time-focus of the beam on the stripping foil to reduce the emittance growth due to energy straggling. The chopper is specified to have two modes of operation one giving bunch spacing of 85 ns at 75% efficiency and the other a bunch spacing of 170 ns at 38% efficiency. The chopper consists of a series of two sets of plates located in a location where horizontal divergence has been minimized followed by selecting slits near the stripping foil a 90° phase advance downstream. Each plate pair has one plate driven at rf voltage (11.8 MHz and 5.9 MHz respectively) and the other compensating plate is dc biased to produce zero deflecting field at the base of the rf waveform to reduce transverse emittance growth. In the first mode the two 35.4 MHz side-bands in the pulse structure (Fig. 3(a)) are deflected at 11.8 MHz (Fig. 3(b)). In the second mode the side-bands plus every second main pulse are deflected by adding the 5.9 MHz deflection (Fig. 3(c)) from the second set of plates to yield the combined deflecting field shown in Fig. 3(d). Beam simulations show that such a chopper should not increase either the transverse or longitudinal emittance. The chopper plate assembly has been fabricated and the two lumped circuits to drive the plates to $\sim 7 \text{ kV}$ are being developed.

2.4 DTL

The variable energy DTL[5] is based on a separated function approach with five independent interdigital H-mode (IH) structures, each with 0° synchronous phase, providing the acceleration and quadrupole triplets and three-gap bunching cavities[4] between tanks providing transverse and longitudinal focussing respectively. The DTL is designed to efficiently accelerate low- β heavy ions over a large operating range while maintaining high beam quality. The IH tanks consume only 60 kW of rf power to produce a total accelerating voltage of 8.1 MV over the 5.6 m length.

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. Measurements confirm that variable energy operation works as predicted[6]. Results from a beam of $^4\text{He}^{1+}$ are given in Fig. 4 showing the energy spectrum for five different Tank1 settings. The longitudinal emittance is measured to be $\sim 0.5\pi\text{keV/u-n}$ s for all cases in agreement with beam simulations. Transverse emittance growth is minimal.

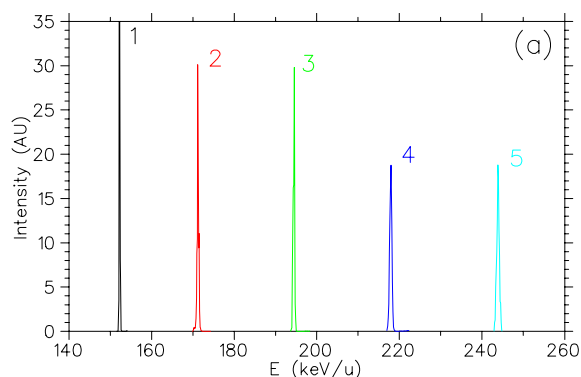


Figure 4: Beam results giving final energy and TOF spectra for five sample energies covering the full accelerating range of the first DTL subsection.

The remaining four sub-sections of the DTL are in various stages of assembly[3]. Installation will begin in Sept. 2000 with the full DTL ready for first beam by Dec. 2000.

2.5 HEBT

The HEBT installation is in progress with the initial installation feeding two target stations 23.1 m and 30.2 m downstream of the DTL respectively. A diagnostic station consisting of transverse emittance rig and 90° analyzing magnet will be installed downstream of the DTL. A low- β ($\beta_o = 0.022$) 11.8 MHz rebuncher and a high- β ($\beta_o = 0.032$) 35.4 MHz rebuncher are positioned on either side of a double focus positioned 11.8 m downstream of the DTL. The 11.8 MHz rebuncher[7] is a three gap structure driven by two lumped element circuits with up to 30 kV required on each drift tube. The 35.4 MHz buncher is a two-gap spiral device similar to the MEBT rebuncher with

170kV required on the drift tube. The HEBT line including bunchers is scheduled for beam commissioning early in 2001.

3 ISAC-II STATUS

Federal funding for the ISAC-II project is now in place as part of the TRIUMF five year funding cycle from April 2000 - April 2005.

The specification of the superconducting linac calls for three cavity types of frequency (β_o) 70.7 MHz (4.2%), 106.08 MHz (7.2%) and 141.4 MHz (10.5%) respectively. A medium β quarter wave bulk Niobium cavity[8] has been designed in collaboration with INFN-Legnaro and is now in fabrication. The cavity is shown in Fig. 5 along with some design parameters. RF tests should begin early next year in Legnaro. A superconducting rf test lab is now being planned at TRIUMF. A first stage of the superconducting linac consisting of twenty mid- β cavities is planned for 2004. A collaboration on the ECR charge state booster has just been initiated with ISN Grenoble.

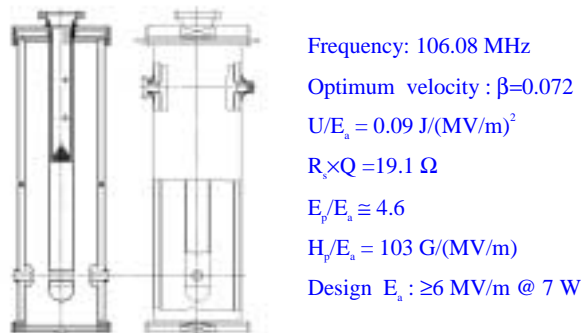


Figure 5: The prototype 106.1 MHz medium- β cavity for the ISAC-II project at TRIUMF.

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