A POST ACCELERATOR FOR A RADIOACTIVE BEAM FACILITY AT TRIUMF

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Abstract

Installation of a post-accelerated radioactive beam facility (ISAC) has been proposed at TRIUMF. The accelerator specifications call for acceleration of ions with charge to mass ratios greater than 1/60, to energies up to 1.5 MeV/u in one beamline, and up to 10 MeV/u in a second beamline. The current accelerator concept is a three stage linac in which two strippers, a gas canal after the first stage at 60 keV/u, and a carbon foil after the second stage at 1.5 MeV/u, are used to increase the ion charge state. The first stage is a RFQ operating cw at 25 MHz, while the second and third stages, operating at successively higher frequencies of 50 MHz, 75 MHz, and 125 MHz, are a series of independently driven quarter-wave resonators similar to those used for the ATLAS accelerator at ANL and the post-tandem booster at JAERI. Design problems and expected performance are discussed.

Introduction

A radioactive beam ISOL facility with a post accelerator was first proposed at TRIUMF in 1985 [1]. The specifications dictated primarily by the astrophysics interests, required a maximum energy of only 1 MeV/u for ion beams with A ≤ 60. Although the full project was not funded at that time, an on-line target-ion source and mass separator test facility was installed on one of the proton beamlines of the TRIUMF cyclotron and at the same time some accelerator studies were continued, in particular to investigate suitability of superconducting accelerator structures for acceleration of the very low charge to mass ratio particles in this application[2]. In 1993 preparation of a new proposal for a larger facility than that envisaged in 1985 was begun, with the intention of submission to our funding agency in early 1994. The beam specifications for this new proposal are summarized in Table 1.

TABLE 1
ISAC Post - Accelerator Basic Specifications

Input Beam:	
Energy	60 keV
Ion Mass	A ≤ 60
Ion Charge	1^+, or 1^-
Beam Current	< 1 μA dc
Beam Emittance (normalized)	0.25 π mm mr
Accelerated Beam:	
Output Energy: (beamline 1)	.2 MeV/u ≤ E ≤ 1.5 MeV/u
(beamline 2)	~1.5 MeV/u ≤ E ≤ 10 MeV/u
ΔE/E	10^{-3}
Duty Factor	100 %

Because of the cw operation of the TRIUMF cyclotron, radioactive ions are produced continuously in the on line target/ion source. To make most efficient use of the relatively low intensities of the separated ion species, cw rather than pulsed operation of the post accelerator is also desirable.

Conceptual Design

General Description

The block diagram in Fig.1 illustrates the three stage linear accelerator that would satisfy the ISAC specifications in Table 1. Initial acceleration of the singly charged ion beam delivered from the mass separator is accomplished in a RFQ. As a consequence of a fixed 60 kV extraction voltage at the ion source, the ions are delivered from the mass separator with velocities that are mass dependent. To accommodate the ion velocity requirements at the RFQ input therefore, it is necessary to mount it on an insulated deck, and operate it with a dc bias, adjustable between ±60 kV, so that the ion input energy can in all cases be 1 keV/u (for A ≤ 60). After acceleration to 60 keV/u in the RFQ, the beam passes through the first of two matching and stripper sections where its charge to mass ratio is increased to ≥1/20 and then injected into the first stage of a three stage superconducting linac consisting of a series of independently driven accelerator modules, operating at successively higher frequencies of 50 MHz, 75 MHz, and 125 MHz. The first stage accelerates the beam to 382 keV/u. At this point the beam is sufficiently well bunched to allow a transition to a smaller accelerator structure operating a 75 MHz. A matching section consisting of two superconducting solenoids and a superconducting buncher is however necessary to match the beam to the 75 MHz second stage which then accelerates it to 1.5 MeV/u. Here the beam is either transported to the nuclear astrophysics experimental area or it passes through the second stripper to increase the ion q/A to greater than 18/60, before being deflected 90° into an achromatic and isochronous beam transport system that matches it to the final accelerator stage where it is accelerated to energies up to 10 MeV/u.

RFQ and First Stripper

In our initial studies design parameters for the RFQ were determined with the aid of the Los Alamos codes RFQUIK, and PARMTEQ [3]. As pointed out by Staples [4] the use of the preprocessor RFQUIK doesn't necessarily lead to the best design in cases where very small beam currents are involved and space charge is not a problem. The preprocessor GENRFQ [5] in such cases allows greater flexibility in tailoring the bucket size in longitudinal phase space to match the beam size and thus limit longitudinal emittance growth. This provides a better quality beam to the user and makes the higher energy accelerator sections easier to design because of a reduction in debunching in the drift spaces between accelerator sections. Table 2 summarizes the RFQ parameters [6]. By choosing a relatively low operating frequency of 25 MHz, adequate transverse focusing can be achieved with the relatively low vane voltage that is desirable from longitudinal emittance considerations. In this reference design the RFQ has a transverse acceptance of .79 π mm-mrad (normalized), and a capture efficiency of 89%.

A stripper stage follows the RFQ. In view of the relatively low RFQ output energy, the required stripper thickness of less than 0.5 μg/cm^2 to achieve an equilibrium charge distribution, is best realized with a differentially pumped gas canal. This is located in a one metre drift space at a double waist in the five metre long beam transport section,

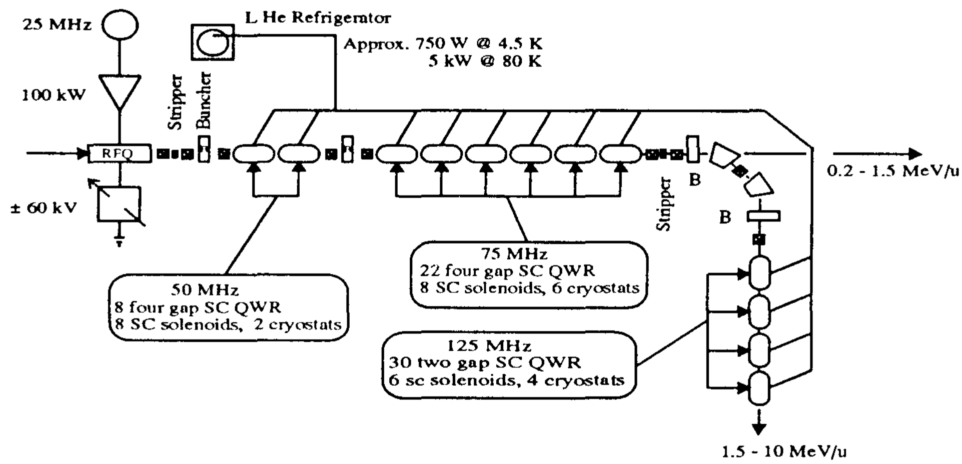

Fig. 1 The ISAC Post Accelerator Concept

TABLE 2
RFQ Parameters

Ion q/A	≥ 1/60
Input Energy	1 keV/u
Output Energy	60 keV/u
Operating Frequency	25 MHz
Vane Voltage	76 kV
Ave. Aperture (r_0)	.78 cm
Focusing Parameter (B)	2.99
Vane modulation factor (m)	2.49
Synchronous Phase	- 90° (initial) - 30° (final)
No. Cells	308
Length	7.56 m

consisting of two quadrupole doublets, a rebuncher cavity, and a quadrupole triplet, that matches the beam both longitudinally and transversely to the first stage of the superconducting linac.

Drift-Tube Linac Stages

The superconducting drift-tube linac stages are based on structures used in the positive ion injector of the ATLAS accelerator at the Argonne National Laboratory [7] and for the post tandem booster at the Japan Atomic Energy Research Institute [8]. Both are basically quarter-wave resonators, capacitively loaded either with a bifurcated drift-tube to form four accelerating gaps, in the case of the ANL structures, or with a single drift-tube to form two gaps in the case of the JAERI structures. The structures are made of niobium and niobium clad copper, and are cooled with pool boiling liquid helium in the centre conductor. Superconducting solenoids are used for transverse focusing. To limit debunching and therefore maintain the necessary longitudinal acceptance, spaces between individual resonators, must be less than 50 cm in first DTL stage. Allowing for mechanical clearance and magnetic shielding at each end of the solenoid, this then means solenoids can have an effective length of no more than about 25 cm. Even with a solenoid lens of this length following each four gap accelerator module, and a relatively small synchronous phase of -20 deg., the initial accelerating gradient had to be limited to 3 MV/m so the rf defocusing in the accelerating gaps could be accommodated. In the other superconducting stages, however, the design accelerating gradient is allowed to rise as high as 5 MV/m. Tables 3 and 4 summarize the main DTL parameters for production of beams with energies of up to 1.5 MeV/u and 10 MeV/u respectively.

TABLE 3
ISAC Post Accelerator
DTL Stages 1 & 2: Ion q/A ≥3/60

	Stage 1	Stage 2
Structure	4 gap QWR	4 gap QWR
Frequency MHz	50	75
Number of Resonators	8	22
E_{acc} MV/m	3 - 5	3 - 5
ϕ_s	-20°	-20°
E_{out} MeV/u	0.382	1.50
βout	0.0285	0.0565
Overall length	11.6 m	14.4 m
Focusing	Superconducting Solenoid	
Solenoid Length	15 cm - 25 cm	30 cm - 105 cm
B_{sol}	6.5 T	6.5 T
Periodicity	Res - Sol - Res	3 Res - Sol - 3 Res

Beam Dynamics Calculations

Particle tracking calculations through the linac were done with the aid of the computer codes PARMTEQ for the RFQ and PARMILA [9] for the DTL stages. For a monoenergetic dc beam, with a normalized transverse emittance of .3π mm.-mrad as input to the RFQ, the PARMTEQ calculations predict an RFQ output beam with a longitudinal emittance of 2.4π keV/A·ns within the 100% contour (1.0π keV/A·ns within the 95% contour), and little transverse emittance growth. Using the PARMTEQ output as input to a modified version of PARMILA that allows tracking of the beam through the stripper/matching sections and the multi-tank DTL with inter-tank beam transport elements (solenoids and drift spaces in this case) we obtain Fig. 2 which shows the calculated transverse and longitudinal phase space plots for the beam emerging at

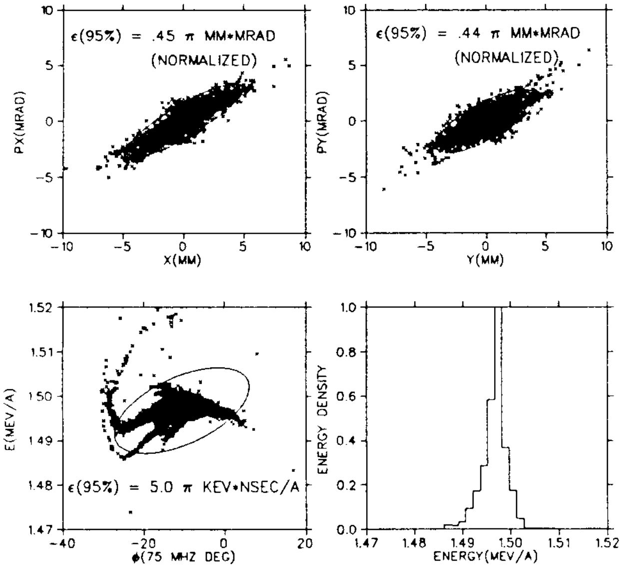

Fig. 2 Calculated transverse and longitudinal phase space scatter plots at the exit of the 1.5 MeV/u linac stage.

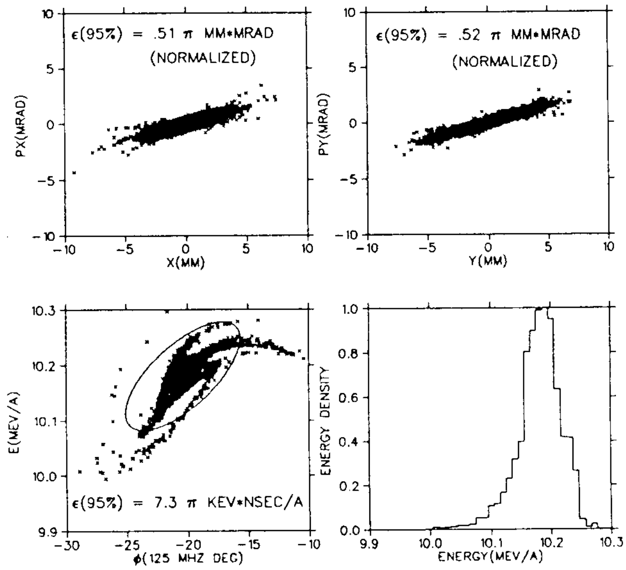

Fig. 3 Calculated transverse and longitudinal phase spase scatter plots at the exit of the 10 MeV/u linac stage

1.5 MeV/u from the second DTL stage. As can be seen, the transverse and longitudinal emittances of this beam, i.e. the one that would be delivered to the astrophysics experimental area, is 0.45 π mm•mrad (normalized) and 5π keV/A•ns respectively. After passing through the second stripper/matching section and acceleration to 10 MeV/u in the third DTL stage, the calculated beam phase space plots, as shown in Fig. 3, are obtained. The longitudinal emittance in this case is 7.3π keV/A•ns. Overall transmission through all linac stages, exclusive of stripper losses, is 75%.

TABLE 4
ISAC Post Accelerator

DTL Stage 3: Ion q/A ≥ 18/60	
Structure	2 gap QWR
Number of Resonators	30
Frequency MHz	125
E_{acc} MV/m	5
ϕ_s	-20°
β_{out}	0.145
E_{out} MeV/u	10
Overall length	12.5 m
Focusing	Superconducting Solenoid
Solenoid Length	13 cm
B_{sol}	6.5 T
Periodicity	6 Res - Sol - 6 Res

Current Status

The full ISAC project with the accelerator described here, would have been a major facility expansion at TRIUMF. Unfortunately budget exigencies have precluded proceeding with the project at this time. Instead, therefore, to satisfy the most important needs of the astrophysics users as well as some others, it is proposed to upgrade the target, ion source and mass separator of the existing TISOL facility and add to this a post-accelerator capable of accelerating particles with q/A ≥ 1/30 to 1.5 MeV/u.

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