

A LOW-CHARGE-STATE INJECTOR LINAC FOR ATLAS

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The design of a low-charge-state linac which is capable of accelerating, for example, $^{132}\text{Sn}^{1+}$ for injection into the existing heavy-ion linac ATLAS is discussed. The injector linac is intended for radioactive beam applications, and will accelerate a low-charge-state beam to energies of 500 keV/nucleon, at which point the ions can be stripped to charge states sufficiently high to be injected into ATLAS. A primary design goal has been to extend the very good longitudinal beam quality typical of ATLAS to low charge state beams. The proposed injector linac consists of several elements. First is a gridded-gap four-harmonic buncher and a short (normally-conducting) 12 MHz RFQ structure, both operating on a 350 kV open-air variable-voltage platform. Then comes an array of 24 Mhz and 48 Mhz superconducting interdigital accelerating structures interspersed with superconducting quadrupole transverse focusing elements. Numerical ray-tracing studies indicate that a transverse acceptance greater than 0.25π mm-mrad can be obtained while simultaneously limiting longitudinal emittance growth to a very few keV-nsec.

I. INTRODUCTION

This paper discusses the front-end of the secondary-linac portion of a proposed ISOL-type radioactive beam facility, an overview of which is presented elsewhere at this conference [1]. The proposed facility would use the existing ATLAS superconducting heavy-ion linac as an accelerator for radioactive beams. In its present form, ATLAS can accelerate any ion with a sufficiently high ($q/A > 0.1$) charge state [2]. For efficient production of most radioactive beams, much lower charge states must be accelerated, at least for the first few MV of the linac. Adapting ATLAS to radioactive beams, therefore, requires development of a low-charge-state injector linac capable of maintaining the good features of ATLAS, particularly excellent beam quality, large transverse acceptance, and flexibility in configuration.

The size of the injector is determined initially by the mass range and type of ion source, and subsequently by the type, number, and location of charge-strippers. Choice of the type, number, and location of strippers involves a complex balance of factors which determine the beam intensity, beam quality, and size and cost of the required linac for the various possible radioactive nuclei. The options chosen here are discussed in reference [1] and also below.

An important technical challenge is to design a linac for low-charge-state ions which can provide simultaneously both large transverse acceptance and also low longitudinal emittance growth (i.e. good time and energy resolution). Large transverse acceptance facilitates high transmission and ease of tuning which will be particularly important when dealing with very low current radioactive beams.

Large transverse acceptance will also enable good matching to a variety of ion sources. The ability of the linac to maintain small longitudinal emittance (ϵ_l of a few tens of π keV-nsec), even for beams of large transverse emittance, will be critical in enabling experiments to use time-of-flight techniques while simultaneously providing good energy resolution and adequate beam intensity.

II. LINAC CONFIGURATION

The low-charge-state injector linac requires strong transverse focusing at low velocities. For the charge states considered here ($q/A = 1/66$) the 8T solenoid lenses used in the present ATLAS heavy-ion linac are inadequate. Substantially stronger focusing is obtained with either magnetic or electric quadrupole lenses. We are developing a superconducting magnetic quadrupole element which is discussed elsewhere at this conference [3]. This quadrupole, operating at 350 T/m over a 3 cm diam. bore, provides sufficient transverse focusing to base a linac on the same high performance 48 MHz superconducting drift-tube structures that were previously developed for the ATLAS positive ion injector linac [4].

Figure 1 shows a possible configuration for the injector linac: it consists of three distinct sections. The first is a two-meter long, normally conducting, 12 MHz RFQ accelerator section, operating on a 350 kV variable voltage platform. The second section is a short (1.5 m) drift-tube linac, for which we propose to use 24 MHz superconducting drift-tube structures. The third section constitutes 90% of the injector linac and is an array of 40 superconducting 48 MHz interdigital cavities.

Note that the beam is stripped from a $1+$ to a $2+$ charge state at the exit of the RFQ section. By using a non-equilibrium, thin gas stripper at this point, it should be

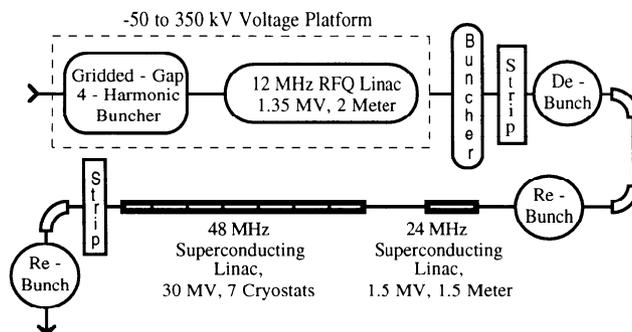


Figure 1: Elements of the low-charge-state injector linac. 1^+ ions at 100 kV are accelerated to energies of 500 keV/nucleon or more, then stripped for injection into the existing ATLAS accelerator. Ions with mass > 70 require an additional stripping immediately following the RFQ section

possible to strip as much as 50% of the beam into a 2+ charge state [1]. Stripping this early in the acceleration process reduces the size of injector linac required while keeping a large fraction of the incoming beam.

A. The Entrance RFQ Section

At an entrance energy of a few hundred keV and charge state 1+, an electric quadrupole provides the strongest transverse focusing. This favors the choice of an RFQ type accelerating structure at the beginning of the linac. For the present application, however, it is highly desirable to maintain a substantially smaller longitudinal emittance than is typical for RFQ implementations. Several features of the design presented here ensure this result.

A separate, gridded-gap bunching system can maintain the longitudinal emittance at a smaller value than is practicable using adiabatic bunching within the RFQ structure itself [5]. Also, by removing the bunching function, the length of the RFQ is reduced and the efficiency enhanced. Placing both the buncher and the RFQ on a variable voltage platform allows operation with a constant velocity profile for a wide range of ion masses. The 12 MHz gridded-gap, four-harmonic bunching system which is presently in use on the ATLAS accelerator would be suitable for this application: this system can bunch up to 70% of a dc beam into 1 nsec bunches. The efficiency could be further improved by development of a finer grid structure.

The RFQ should operate at as low a frequency as is practicable both to minimize longitudinal emittance growth and also to maximize the transverse acceptance. The split-coaxial RFQ geometry is appropriate for this frequency range; RFQ structures have already been developed at nearly the frequency and field required here. The MAXILAC linac developed at GSI operates at 13 MHz and provides both design concepts that can be adapted to the present application, and also a demonstration of the required performance [6]. We propose an RFQ structure with electromagnetic parameters close to those of the MAXILAC, but with a substantially different vane design. In particular, the vanes should be continuous, e.g. milled from one piece of metal. Also, sufficient water cooling should be included to provide good thermal stability during cw operation.

We have numerically modelled an RFQ structure with the following parameters:

Operating frequency	12.125 MHz
Maximum vane voltage	100 kV
Maximum Electric field	12.8 MV/m (1.2 Kp)
Minimum Aperture	8.00 mm
Modulation factor	1.5
Entrance Velocity	0.0024 c
Exit Velocity	0.0047 c
Number of cells	44
Length	198.2 cm
Synchronous phase	- 30 degrees

The RFQ is designed for a minimum charge to mass ratio of 1/132: ions of higher charge state are accommodated by simply scaling both the platform voltage and the RFQ voltage to match. The peak electric field was determined numerically using the RELAX 3D code for a realistic vane geometry. It should be noted that while it seems feasible to obtain a cw vane voltage of 100 kV (based on the present performance of MAXILAC), the beam quality would remain acceptable for a vane voltage below 50 kV

Numerical ray-tracing in three dimensions has been performed for the above design, using a two-term potential approximation. Shown in Figure 2 are some results for a beam of 0.25π mm-mrad transverse emittance (the maximum specified for a benchmark facility by the North American Steering Committee for an Isospin Laboratory) [7].

B. Superconducting Linac Using a Magnetic Quadrupole Lens

We have evaluated the performance of linac sections based on superconducting interdigital (drift-tube) cavities and a 350 T/m, 3 cm diameter bore quadrupole magnet described elsewhere at this conference [4]. The magnet is employed in the form of a triplet lens with an overall length of approximately 26 cm. The linac lattice in all cases consists of a triplet following each superconducting four-gap accelerating structure. Numerical ray-tracing was performed using a cylindrically symmetric approximation to

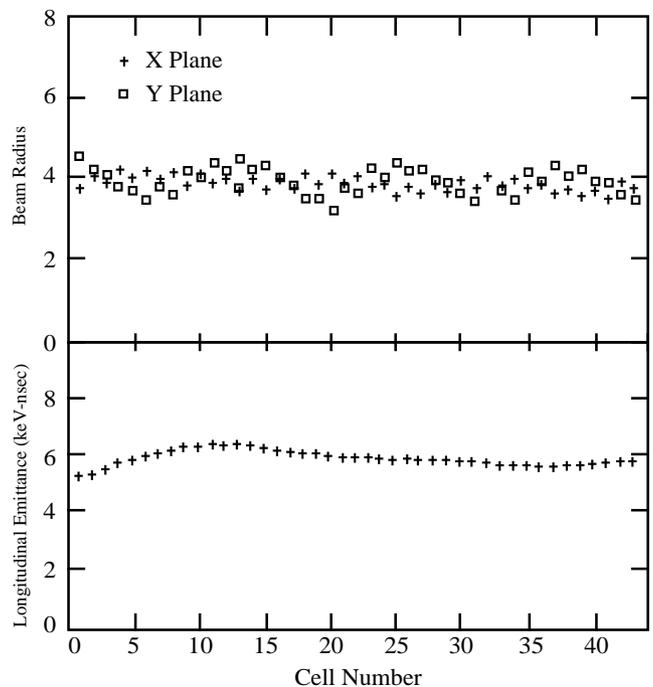


Figure 2: Transverse beam size and longitudinal emittance for a $q/A = 1/132$ beam with 0.25π mm-mrad transverse emittance accelerated through a 2 meter long, 44 cell RFQ operating at 12.125 MHz.

the electric fields in the superconducting drift-tube structures, and quadrupole fields in the magnets.

We consider first a 48 MHz linac section, consisting of forty interdigital cavities and forty triplets. This linac can accelerate any beam with $q/A \geq 1/132$ over the velocity range $.008 \leq \beta \leq .033$. Figure 3 shows the results of numerical ray tracing for a $^{132}\text{Sn}^{2+}$ beam of transverse emittance $\epsilon_T = 0.25 \pi$ mm-mrad [8]. The longitudinal emittance growth through the linac is negligible. In fact, the transverse acceptance of this section is greater than 0.6π mm-mrad, and even for such a large beam the longitudinal emittance growth is small.

Any of several linac structures could be used for accelerating a 2+ charge state beam over the velocity range $.004 < \beta < .008$ following the stripper at the exit of the RFQ to the entrance of the 48 MHz superconducting linac. A possibility considered here is a five resonator array of 25 MHz superconducting drift-tube structures.

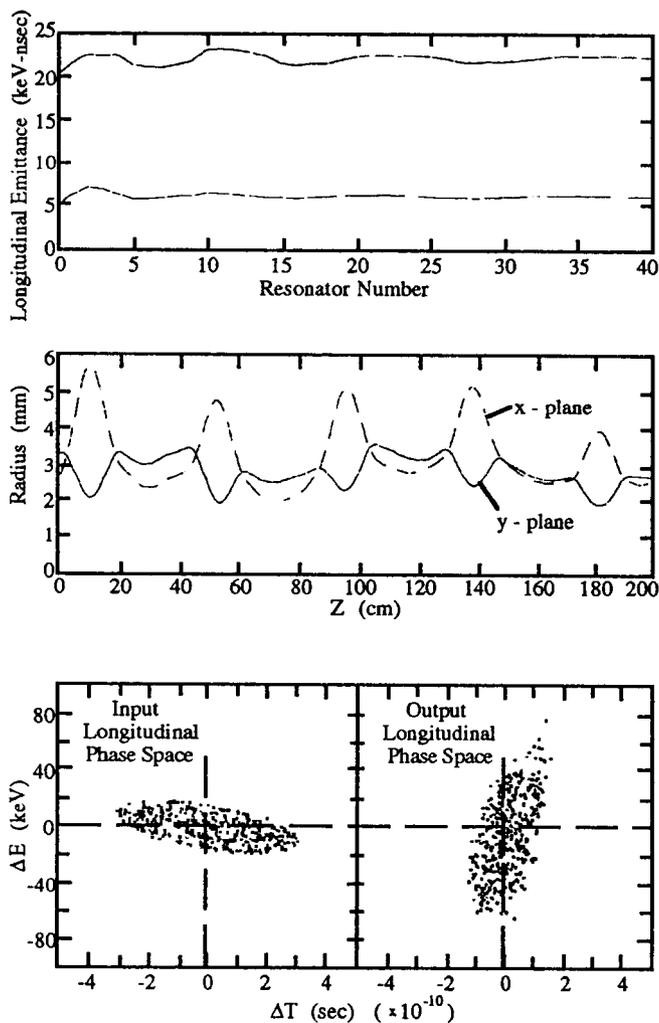


Figure 3: Transverse beam size (for the first 4 cells) and longitudinal emittance for a $q/A = 1/66$ beam traced numerically through a 40 cell superconducting drift-tube linac using magnetic quadrupole focusing. The normalized transverse emittance is 0.25π mm-mrad.

Adequate mechanical stability can be obtained using a folded coaxial line structure (recently implemented as a 25 MHz normally conducting accelerating structure) [9]. The folded line needs have no element longer than $1/8$ wave, and provides mechanical stability comparable to existing 48 MHz drift-tube structures while reducing the frequency a factor of two. Preliminary numerical ray-tracing has been performed for an array of five such 24 MHz cavities, using the above described 350 T/m quadrupole triplet for transverse focusing. For a $^{132}\text{Sn}^{2+}$ beam of transverse emittance $\epsilon_T = 0.25 \pi$ mm-mrad, an acceptably small longitudinal emittance growth of 3 keV-nsec was calculated for a beam with an input emittance of 5 keV-nsec.

III. CONCLUSIONS AND ACKNOWLEDGMENTS

A low -charge-state injector linac has been designed capable of accelerating beams of $q/A \geq 1/132$. The linac exhibits a transverse acceptance greater than 0.25π mm-mrad with a longitudinal emittance growth of no more than a few keV-nsec. The injector would adapt the ATLAS accelerator to the very low charge state ion beams required for radioactive beam applications, while maintaining the present beam quality. Formed of an array of independently-phased superconducting drift-tube structures, the linac would permit the same flexibility in configuration that has characterized the ATLAS accelerator.

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