DESIGN STUDY OF A SUPERCONDUCTING LINAC FOR RIA*

J. Kim, D. Gorelov, F. Marti, H. Podlech, X. Wu, and R. York, NSCL/MSU, East Lansing, MI 48824, USA

Abstract

The proposed Rare Isotope Accelerator Facility (RIA) requires a heavy-ion driver linac capable of accelerating uranium to 400 MeV/u with the beam powers of 100 to 400 kW. The beam power requirement will be met for very heavy ions by simultaneous acceleration of multiple charge states because of ion source limitations. To minimize the number of accelerating structures, two charge stripping stations have been proposed for nuclei heavier than Kr. The intensity loss due to multiple stripping is minimal by the multiple charge acceleration. However, the technical challenges and concomitant risks of the stripping stations for the proposed beam powers are significant particularly at the lowest energy. As a consequence, an alternative layout with only one stripping station at a point about twice the energy of the lowest energy of the two-station scenario is proposed. This scheme removes one stripping system, but increases the installed accelerator requirement by about 10 %. The beam dynamics of the driver linac has been studied using a newly written single particle tracking program as well as other extant programs.

1 INTRODUCTION

The Rare Isotope Accelerator (RIA) recommended by the nuclear science community requires a driver linac that can accelerate all stable nuclei [1]. The linac design is primarily driven by consideration of uranium acceleration to 400 MeV/u with a beam power of at least 100 kW. The beam power for such heavy ions is limited by the ion source performance, but the simultaneous acceleration of multiple charge states will provide the required beam current and mitigate the intensity loss usually incurred when the stripping to higher charge states is employed to minimize the installed voltage requirements.

For nuclei heavier than Kr, a possible RIA driver linac [2] would employ charge stripping at two positions corresponding to uranium energies of approximately 13 MeV/u and 85 MeV/u. Due to technical risks and possible operational uncertainty of charge stripping of heavy ions at the proposed beam powers, an alternative linac configuration using only one charge stripper at an energy of about 25 MeV/u has been investigated.

For the low energy section of the linac, superconducting solenoids similar to those used at ATLAS [3] are the most economical focusing elements. For energies higher than about 100 MeV/u, normal-conducting quadrupoles like those of the SNS proton linac [4] are preferred. Either type of focusing element could be considered for the intermediate energies. An initial analysis of the focusing lattice for the linac beyond 25 MeV/u including the choice of solenoids or quadrupoles and alignment sensitivity has been done.

A new program was developed for this study based on an orbit-tracking program used in the design of low energy heavy ion accelerators ATLAS and Positive Ion Injection linac [5]. The program tracks particles through the linac elements using realistic rf electric fields of each resonator. The code has been modified to be modular for different elements and to track particles in rectangular coordinates.

2 ACCELERATOR LAYOUT

One of the key RIA linac optimizations is minimization of the total acceleration voltage by optimization of the stripping energies. Only a single stripper is required if the expense of about 10% increase is acceptable in the number of accelerating structures when compared to a design with two strippers. For sites requiring a folded linac, the two-stripper scheme may be particularly suitable allowing the linac layout to be folded. However, elimination of the higher-energy charge stripping stage may increase operational reliability and reduce significant maintenance efforts. In addition, there would be some improvement in the beam quality for the single stripper case.

The linac layouts for two different schemes are shown schematically in Fig. 1, and the numbers of required cavities are tabulated in Table 1 assuming rf structures as in reference [6]. For lower stripping energies in the single stripping case, the number of higher beta cavities increase, whereas for higher stripping energies, the number of lower beta cavities becomes larger. An energy of 25 MeV/u is chosen for the present study.

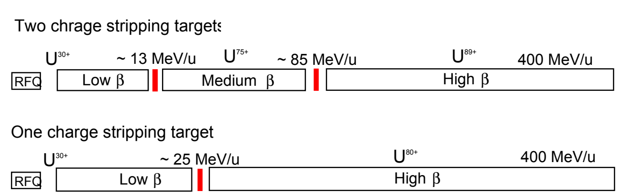

Figure 1: Layouts of heavy-ion driver linacs from the RFQ linac in the single and double charge stripping cases for very heavy ions.

* Work supported by NSF Cooperative Agreement # PHY-952844

Table 1: Numbers of rf cavities needed to accelerate a uranium beam to 400 MeV/u using different charge stripping energies.

Charge Stripping Energy (MeV/u)	**# of cavities**	**# of cryostats**
13 & 85	435	77
20	476	83
25	479	82
30	491	83

The beam dynamics code for this study was based on an existing tracking program extended to track particles in rectangular coordinates and to include quadrupole and other elements. Relativistic corrections were also applied to the equations of motion. In addition, to expedite the inclusion of new elements, the structure of the code was modularized. The assumed axial symmetry of the cavity fields valid near the beam region was retained. An accelerator layout including cavities, focusing elements and cryostats is generated from the code input allowing easier configuration optimization.

At the charge stripper a spectrum of charge states is produced. The width of charge state distribution around an equilibrium charge state has been estimated using semi-empirical formula [7]. For example, five charge states around q=80 at 25 MeV/u roughly contain 80 % of the uranium beam and seven charge states contain 85 %.

The upper plots of Fig. 2 are for the case of a single charge stripping station at 25 MeV/u. The longitudinal phase space of a uranium beam at 0.17 MeV/u, 25 MeV/u with two charge states and at 400 MeV/u with five charge states are shown. The initial longitudinal rms emittance is 0.2 π keV/u·ns at 0.17 MeV/u. The emittance increase due to stripping is included in the simulation. The lower plots of Fig. 2 are for the case of two stripping stations. The longitudinal phase space of the uranium beam is given at 13 MeV/u with two charge states, at 85 MeV/u with five charge states and at 400 MeV/u. The longitudinal emittance at 400 MeV/u for the single stripping is 1.4 π keV/u·nsec whereas it is 1.9 π keV/u·nsec in the case of two stripping stations.

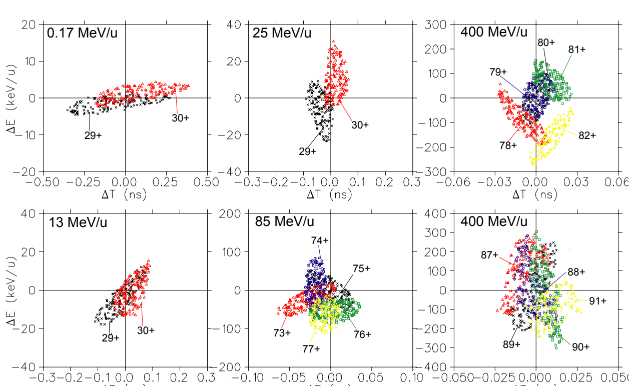

Figure 2: Longitudinal phase spaces at several stages of the linac. Upper plots: single charge stripping station at 25 MeV/u. Lower: two charge stripping stations at 13 and 85 MeV/u.

3 FOCUSING ELEMENTS

In the lower beta region prior to the first charge stripper, superconducting solenoids are appropriate. In the higher beta region where elliptical superconducting cavities of the type used in the SNS linac, normal-conducting quadrupoles are preferred. In the middle either kind could be used. The cryostat configuration is modified according to the focusing element type as shown in Fig. 3. The cavity array was chosen so that the quadrupole option has the same number of cryostats as the solenoid lattice. As a consequence, for the same beam emittance, the beam envelope is larger for the quadrupole lattice. The beam envelopes for the two cases are given in the lower part of Fig. 3 for a normalized rms-emittance of 0.15 π mm·mrad. An even larger beam size would be feasible given the proposed resonator radial beam apertures of 1.5 cm. However, it is prudent to provide an aperture allowance for the effects of misalignments. The normal-conducting quadrupole focusing lattice does provide the advantage of alignment independent of the cryostat.

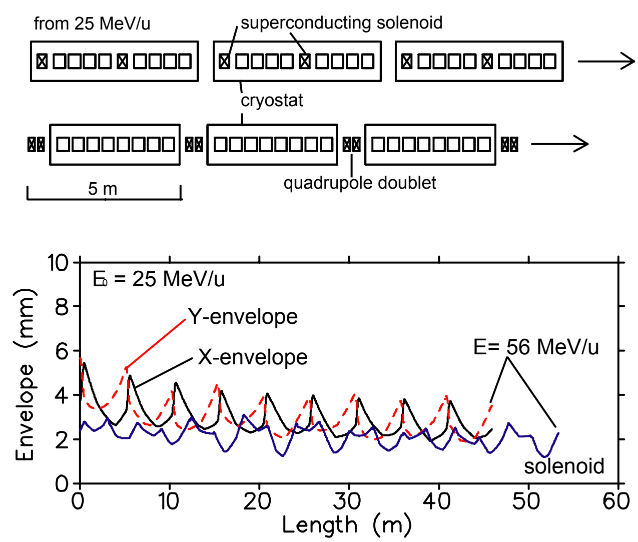

Figure 3: Upper: Two different layouts of focusing elements downstream of the charge stripping section (25 MeV/u) using either superconducting solenoids or normal-conducting quadrupole doublets. The layouts of the elements and cryostats are generated from the input table used for the beam dynamics calculations. Lower: The beam envelopes for a normalized rms emittance of 0.15 π mm·mrad.

4 MISALIGNMENT

Assessment of alignment tolerances on the focusing elements in ion linacs requires elaborate evaluations of the different modes of misalignments. A full assessment requires the inclusion of corrective elements and realistic estimates of element misalignments. This will be the subject of future efforts. An initial evaluation of the effects of focusing element misalignment was done using the linac layouts of Section 3. Figure 4 shows the envelope modulation for a few angular misalignment values using either solenoid or quadrupole elements. The rotation tolerance was explored as it is anticipated to be the more sensitive focusing element alignment criteria. The initial results would support the conclusion that it would be desirable to have the focusing element rotation misalignments at less than 2 mrad. More detailed analysis will be done in the near future.

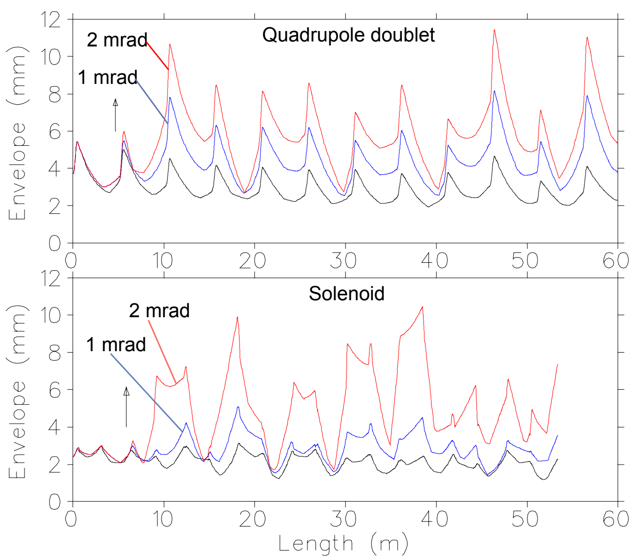

Figure 4: Beam envelopes resulting from rotational misalignment of the focusing elements for values of 0, 1 and 2 mrad. The arrows indicate the locations of misaligned elements.

5 CONCLUSION

A RIA driver linac employing only a single charge stripper may provide design and operational simplifications. However, the initial cost of the linac would be higher than one using two charge-stripping stations because of increase in installed accelerator requirements. A new single-particle tracking program used in this initial analysis will provide a useful linac design tool providing easy design variation and visual representations of hardware layout and beam phase space evolution.

REFERENCES

[1] ISOL Task Force Report to NSAC, http://srfsrv.jlab.org/ISOL/.

[2] P. Ostroumov and K. Shepard, PRST-ST, Vol. 3, 030101 (2000).

[3] A. Jaffey, LINAC'76, Chalk River, (1976) 102.

[4] J. Stovall et al., LINAC'2000, TUD22.

[5] R. Pardo et al., PAC'87 (1987) 1228.

[6] K. Shepard, LINAC'2000, THD08.

[7] E. Baron et al., Nucl. Instr. and Meth. A328 (1993) 177.