01-222N(G) -- CONCEPTS FOR POST ACCELERATION OF MASS 240, 1+ RADIOACTIVE IONS

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Funding Profile:

FY 1999	-0-
FY 2000	-0-
FY 2001	$255K
FY 2002	$310K
FY 2003	$310K

Purpose: Since the early 1990's in the field of low energy nuclear science there has been worldwide interest in an advanced facility capable of producing energetic, high-quality beams of radionuclides. The purpose of this LDRD project is to develop design concepts for the major components of the Rare Isotope Accelerator (RIA). This project aims to develop an efficient post-accelerator for rare isotopes. Since the rare isotopes of interest are most efficiently produced as singly charged ions, the post-accelerator must be able to start accelerating singly charged heavy ions from ion source potential. A continuous low-frequency RFQ structure must be developed for this purpose.

Approach: To most efficiently accelerate the low velocity singly charged heavy ions, a new type of structure is required. A hybrid RFQ structure was proposed for this purpose. A modern post-accelerator for radioactive beam facilities requires acceleration of heavy ions beginning with charge state 1+ in order to maximize the intensity of the beams available for experiments. The acceleration of unstable nuclides with mass number up to 240 is required. For acceleration of low-velocity heavy ions, very low-frequency RFQs are appropriate. However, the accelerating efficiency of such RFQs is low. To overcome this drawback we propose a hybrid accelerating structure that is formed by an alternating series of drift tubes (DTL) and RFQ sections. In such a structure the accelerating and focusing functions are decoupled.

Technical Progress and Results: A hybrid RFQ (H-RFQ) was designed for acceleration of heavy ion beams with q/A=1/240 in velocity range 0.0038-0.0067. The proposed hybrid RFQ structure has the following innovative features compared to conventional RFQs with similar parameters: a) separate sections of drift tube accelerator and RF focusing structures placed inside the same resonant structure producing twice the accelerating gradient; b) focusing provided by four RF quadrupoles operating as a triplet; c) lower RF power consumption per unit length; d) lower peak surface electric fields and less surface area at high electric field.

For CW operation the peak surface field must be chosen very carefully. Our design is based on a 12 MHz accelerating structure with 100 kV between the drift tubes (DT) and RFQ vanes. The peak surface electric field occurs on the vanes of the first RFQ lens

and it is equal to 118 kV/cm. Basic design parameters of the H-RFQ are given in Table 1. Figure 1 shows beam energy vs. distance in the H-RFQ and in a conventional RFQ. The reference RFQ was designed at the same voltage and operating frequency with constant phase advance of transverse oscillations per period equal to 17°. As is seen from Fig. 1 the H-RFQ provides twice as much accelerating voltage.

Table 1: Design parameters of the H-RFQ

Operating frequency	12.125 MHz
Ion species	$^{6}He^{+1}$ to $^{240}U^{+1}$
Beam energy	7 to 20 keV/u
Length	334 cm
Number of drift tubes in three sections	13-10-13
Drift tube aperture radius	1.0 cm
RFQ aperture radius	1.14-1.23 cm
Inter-vane, inter-DT voltage	100 kV
RF power according to the code MWS	11.6 kW
Peak surface field	118 kV/cm

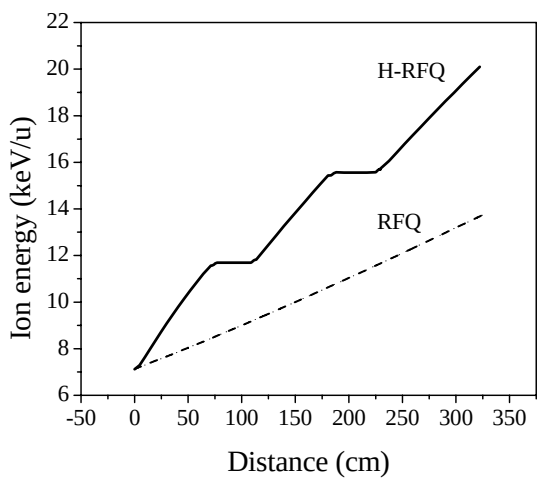

Figure 1. Beam energy as a function of longitudinal distance along the reference RFQ and H-RFQ.

The beam dynamics design of the H-RFQ structure iterated between the two steps: 1) preliminary design of the longitudinal layout and 2) detailed simulation of beam dynamics in 3D electric fields. These steps were iteratively repeated in order to achieve the design goals: minimal emittance growth, lowest possible peak surface field, lowest sensitivity to the misalignments and RF field errors, and maximum possible 6D acceptance. The input beam is formed by the multi-harmonic buncher and a RFQ. These devices are optimized for the formation of the lowest possible longitudinal

emittance. The 12 MHz RFQ upstream of the H-RFQ is a modification of the existing prototype RFQ developed in a previous LDD program with redesigned vanes. The conventional RFQ following the multi-harmonic buncher is still the best option for the formation of the lowest possible longitudinal emittance.

The first DT section of the H-RFQ operates at zero synchronous phase while the last two DT sections operate at –20° synchronous phase. The 1+ rare isotope beams come from either a standard ISOL-type ion source or a helium gas catcher and, therefore, the maximum expected transverse normalized emittance is quite low, ~0.1 π·mm-mrad. Heavy ion beams such as uranium will be formed even with lower normalized emittances, ~0.01 π·mm-mrad. Figure 2 shows the beam envelopes at the $\sqrt{5}\sigma$-level in horizontal, vertical, phase and relative energy planes. The graphs are given for $\varepsilon_{n,\perp}$=0.03 π·mm·mrad and $\varepsilon_{n,||}$=0.1 π·keV/u·nsec. The simulations show that the beam parameters such as average energy, phase spread, emittances, Twiss parameters, etc. experience negligible change if the voltage is varied in the range -3% to +7% from the nominal value.

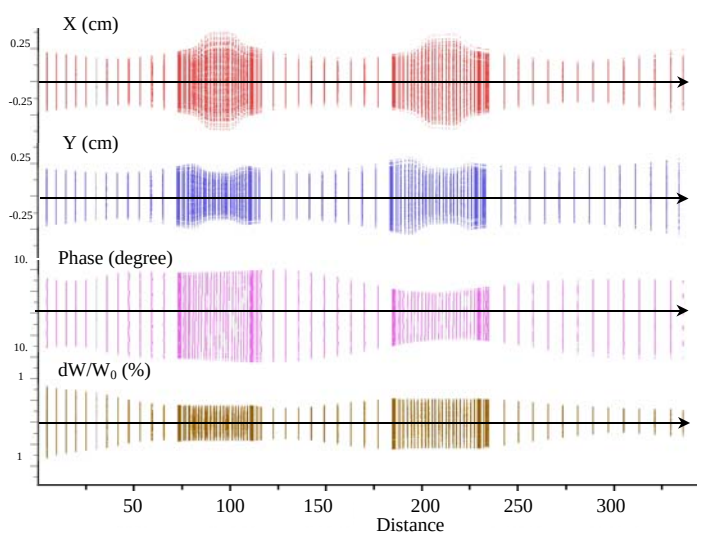

Figure 2. Beam width in horizontal and vertical planes, phase and relative energy spreads along the H-RFQ.

Several resonant structures have been considered as candidates for the H-RFQ. The main specifications for our application are: 1) the structure length ~3.34 m is determined by the given input and output beam energies; 2) the structure should be mechanically stable; and 3) the shunt impedance should be high. Though split-coaxial structures have been used in several low frequency RFQs, the Wideroe-type structure better satisfies the above mentioned conditions. The side view of the accelerating structure used for the electrodynamics simulation by the code Microwave Studio (MWS) is shown in Fig. 3.

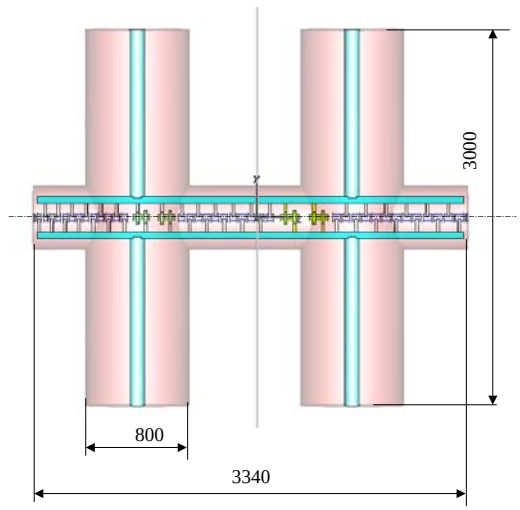

Figure 3. Side view of the H-RFQ resonant structure.

According to MWS the RF losses are 11.6 kW at 100 kV inter-vane voltage in this copper cavity. The losses are lower than in a split-coaxial RFQ of similar length because the total capacitive loading of the drift tubes is about half that of the four-vane structure. Due to the short length of the structure compared to the wavelength, a uniform voltage distribution on all vanes and drift tubes is expected, as shown in Fig. 4.

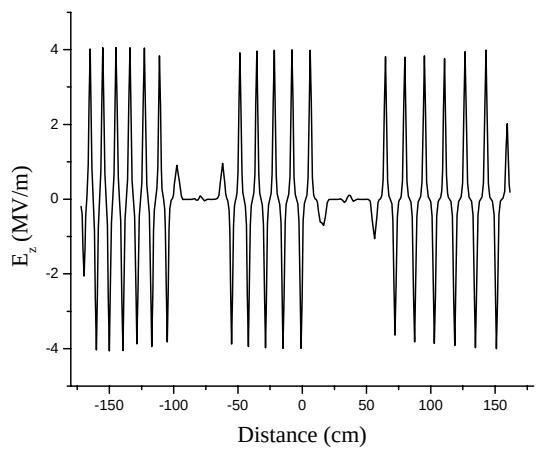

Figure 4. Distribution of the longitudinal component of electric field along the structure as calculated by MWS.

A cold model of the H-RFQ for the RIA RIB linac is under development. A 3D view of the first section of the H-RFQ containing drift tubes and the first set of RF quadrupoles is shown in Fig. 5. The H-RFQ can be used for effective acceleration of low velocity heavy ions in various fields of application, where focusing by electric fields is appropriate.

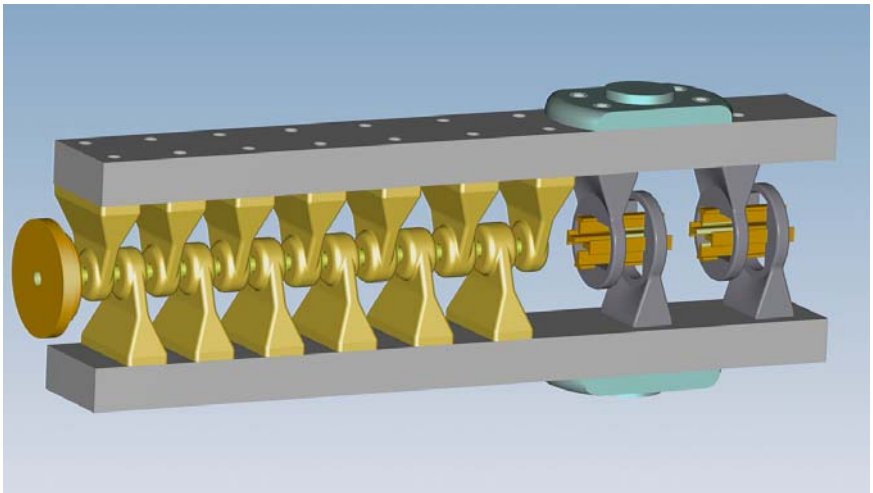

Figure 5. Three-dimensional view of the first drift tube section of the H-RFQ.

Specific Accomplishments: An invention report and a contribution to an international conference resulted from this LDRD effort.

P.N. Ostroumov and A.A. Kolomiets, “Hybrid RFQ Structure for Acceleration of Slow low-Charge State Heavy-Ion Beams,” ANL Invention ANL-IN-01-047.

P.N. Ostroumov and A.A. Kolomiets, “New Concept for Acceleration of Slow, Low-Charge-State Heavy Ion Beams,” 2001 Particle Accelerator Conference (PAC2001), Chicago, IL, June 18-22, 2001, Book of Abstracts, FPAH313, p. 276 (2001).