01-222R1(G) - STUDIES OF A NEW HIGH-EFFICIENCY STRUCTURE FOR ACCELERATION OF RADIOACTIVE IONS WITH CHARGE-TO-MASS RATIO 1/240

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Purpose: The Radioactive Ion Beam (RIB) linac of a rare isotope accelerator (RIA) will utilize existing superconducting heavy-ion linac technology for most of the linac except a very-low-charge-state injector section needed for ~10 MV. This section consists of a pre-buncher followed by three sections of continuous wave (cw), normally-conducting radio frequency quadrupoles (RFQs). The last two sections of the RFQ will be based on a more effective accelerating structure, a hybrid RFQ which provides high-efficient acceleration of well bunched ion beams. We found that the concept of separated accelerating and focusing zones can be applied to the acceleration of heavy ions with $q/m \leq 1/240$ and at very low energies if the beam focusing is provided by rf quadrupoles. The goal of this work is to test the concept of hybrid RFQ and develop a set of specifications for the full power hybrid accelerator to be used in a RIA radioactive beam accelerator.

Approach: Beam dynamics design of the hybrid RFQ was completed in 2001. The design of the resonator has been developed on the base of three-dimensional electrodynamics simulation codes. The goal of the work was to develop and build a 2:1 aluminum cold model of the hybrid RFQ. This goal was successfully achieved. Preliminary measurements of the resonator parameters were made using the bead-pull technique.

Technical Progress and Results: The accelerating and focusing sections of the hybrid RFQ can be integrated into a single resonant structure we call the hybrid RFQ. 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.

In the focusing section of the Hybrid RFQ (H-RFQ) an unmodulated four-vane RFQ forms two sections each with length $\beta\lambda$ separated by a drift space $\beta\lambda/2$. The focusing strength of each RFQ lens with length $\beta\lambda/2$ is adjusted and fixed by the aperture radius R_0. A section of the RFQ with length $\beta\lambda$ acts as a "doublet". The drift space between the "doublet" is necessary to ease the required electric field between the vanes. The whole focusing system works as a symmetric triplet.

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 20% lower than in the existing split-coaxial 12 MHz RFQ built at ANL 5 years ago. The surface field on the drift tubes is kept even lower by selecting long accelerating gaps. The H-RFQ provides twice as much accelerating voltage compared with the conventional RFQ over the same length. In addition the shunt impedance of the H-RFQ is higher.

The beam dynamics design of the H-RFQ structure was performed in 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 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 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 standard ISOL-type ion sources or a helium gas catcher and, therefore, the maximum expected transverse normalized emittance is quite low, ~0.1 π mm-mrad. Heavy beams such as uranium will be formed with even lower normalized emittances, ~0.01 π mm-mrad. 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% of the nominal value.

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 abovementioned conditions. According to the 3D electromagnetic simulation code CST MWS, the rf losses in this copper cavity are 11.6 kW at 100 kV inter-vane voltage. The losses are lower than in split-coaxial RFQ of similar length because the total capacitive loading of the drift tubes is about half that of the four-vane structure.

To determine complete engineering specifications, an aluminum 1:2 model of the H-RFQ for the RIA RIB linac was built (see Fig. 1). Preliminary measurements of electrodynamic properties of the cavity showed reasonable consistency with the 3D simulation code Micro Wave Studio (MWS). The existing codes can not provide good precision of simulations due to the large amount of drift tubes and quadrupoles. Therefore only studies of the cold model will provide complete specifications for the fabrication of a full-power hybrid RFQ. The frequency of the cold model was 8% higher than calculated one. The measured quality factor is ~50% of the simulated quality factor. The quality factor of the cold model will be improved by providing better electrical contacts at the joints. The electric field distribution in the accelerating gaps along the structure is shown in Figure 2. As expected the electric field remains constant along the structure.

The fabrication and testing of the full-power model of the 12 MHz hybrid RFQ is necessary in order to develop a complete engineering concept of the accelerating structures in the front end of the RIB linac. These design concepts will be applied for all three RFQ sections of the RIB linac.

Specific Accomplishments: P.N. Ostroumov (invited talk), Development of Low Charge-to-Mass Ratio Post-Accelerator for the RIA Project, presented at the 17th International Conference on the Application of Accelerators in Research and Industry (CAARI-2002), Denton, Texas (November 12-16, 2002).

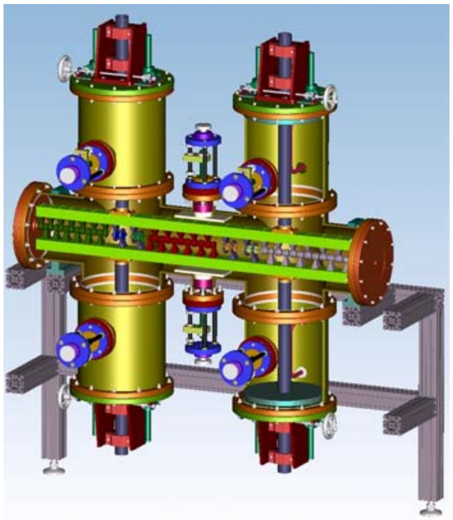

Fig. 1. An engineering three dimensional view (the left picture) and photograph of the 24 MHz H-RFQ cold model.

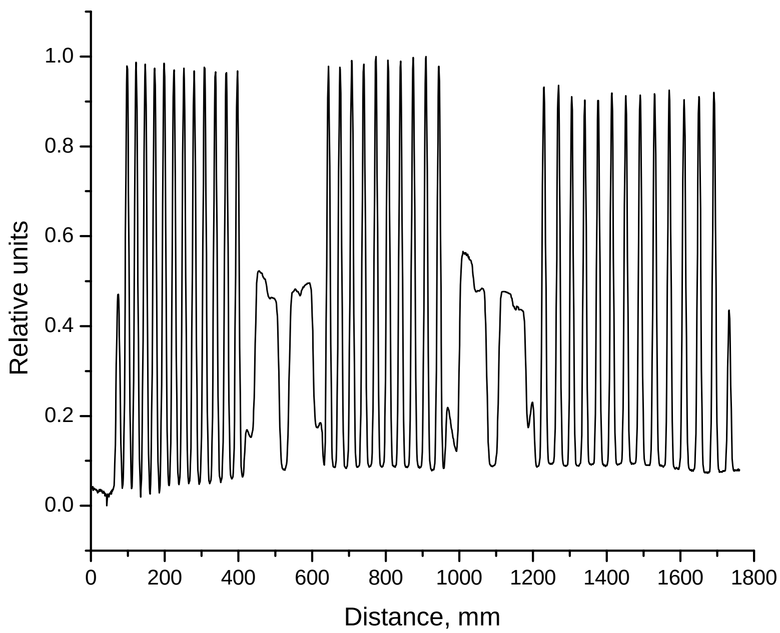

Fig. 2. Electric field distribution along the H-RFQ cold model obtained by bead-pull measurements.