DEVELOPMENT OF ROOM TEMPERATURE ACCELERATING STRUCTURES FOR THE RIA*

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Abstract

The proposed Rare-Isotope Accelerator Facility (RIA) [1] includes a driver linac and a post-accelerator based on superconducting cavity technology. The exceptional sections of the RIA accelerators are front ends that comprise normal-conducting continuous wave accelerating structures to obtain particle velocities acceptable for further acceleration by superconducting cavities. The front ends for both accelerators are based on RFQ technology. An engineering design of a 57.5 MHz RFQ for the driver linac has been developed. A cold model of the 57.5 MHz RFQ has been fabricated.

The post-accelerator consists of a conventional RFQ operating at 12 MHz and two sections of a hybrid RFQ (H-RFQ) operating at 12 and 24 MHz. A 1:2 scale cold model of the 12 MHz H-RFQ has been built and studied to determine the final specifications for the full power hybrid RFQ. This paper reports on the present development status of these accelerating structures.

INTRODUCTION

The primary scope of the driver linac RFQ is the acceleration of low longitudinal emittance dual charge state uranium beams up to energies acceptable by the superconducting linac. In order to simplify the front end of the multi-beam driver linac and accommodate different ion species from the ECR ion source the RFQ must be capable of operating at a wide range of power levels. The physics design of the RFQ beam dynamics and accelerating structure was established earlier [2]. Several types of resonant structures have been analyzed in order to satisfy all specifications. As a result an original RFQ structure that combines the advantages of the four-vane and split-coaxial structures has been proposed in collaboration with ITEP team, Moscow [2]. The structure provides high shunt-impedances, has extremely good mode separation and moderate transverse dimensions ~50 cm at 57.5 MHz operating frequency.

The concept of the RIA post accelerator suitable to produce high-quality beams of radioactive ions over the full mass range, including uranium, at energies above the Coulomb barrier was presented in ref. [3]. The most efficient generation of rare isotope beams requires singly-charged ions at initial injection. Very-low-charge-state ions can most efficiently be bunched and accelerated by using three sections of a cw, normal-conducting RFQ for the first ~9 MV of the post-accelerator. The first two sections of the RFQ should operate at as low a frequency as is practicable to maximize the transverse focusing strength. At ANL the acceleration of $^{132}Xe^{1+}$ ions in the split-coaxial RFQ geometry operating at 12 MHz [4] has been demonstrated. An RFQ for acceleration of heavy ions with a minimum charge to mass ratio of 1/240 will have similar design. The last two sections of the RFQ will be based on a more effective accelerating structure, a hybrid RFQ [5].

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DRIVER LINAC RFQ

Table 1 presents basic parameters of the cw RFQ accelerator that is being designed for the RIA driver linac. The design addresses the requirements for efficient cooling throughout the structure, precise alignment, reliable RF contacts, and fine tuning capability. The RF, thermal and structural analyses have been completed in response to these requirements. Results of these analyses show that the thermal and structural design of this RFQ is very robust [6,7].

Table 1. Basic parameters of the RFQ

Operating frequency	57.5 MHz
Length	4 m
Duty cycle	100%
Transverse dimensions	0.51 m
Peak surface field	140 kV/cm
Input&output particle velocity	0.00507/0.02 c
Design charge-to-mass ratio	1- 28.5/238
Normalized transverse emittance	0.5π mm·mrad
Longitudinal emittance at the exit of RFQ for 99.9% of particles,	≤2π keV/u·nsec

A typical segment with cutaway sections to show the cooling passages is shown in Fig. 1. Several different approaches to fabrication of the RIA RFQ were discussed during the conceptual design phase. Ultimately we have chosen a fully brazed assembly using step brazing to fabricate the vanes and quadrant details and finally a complete segment with end flanges. An octagonal cross section of the RFQ tank was accepted as the most appropriate to apply the step brazing technique. This approach borrows heavily from the techniques used successfully on the LEDA RFQ at Los Alamos [8]. The RFQ is designed as a 100% OFE copper structure with GLIDCOP® dispersion strengthened copper end flanges. Six longitudinal segments will be mechanically assembled to form the complete 4-meter RFQ structure.

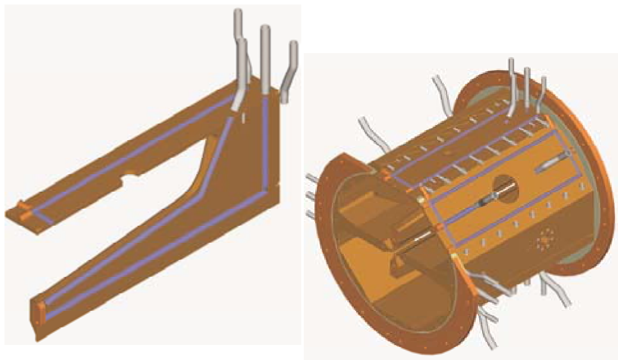

Figure 1. Segment details with cooling channels. The vane assembly is shown separately on the left.

The full-scale aluminum cold model of the RFQ segment was designed and constructed. This model is necessary to verify final internal dimensions of the RFQ prior to the fabrication of full copper structure, and testing of machining and final assembly tolerances. Precise measurements for the gravity deflection of horizontal vane show acceptable deviations of the vane's profile. The final assembly of the model was completed and the specified tolerances on the vane tip location of less than 50 μm were achieved. A photograph of the one-segment aluminum cold model is shown in Fig. 2.

Figure 2. Photograph of the aluminum model.

A full power engineering prototype of a single segment of the 57.5 MHz RFQ is being developed and fabricated. The main reasons to proceed with fabrication and testing of the engineering model are: a) the transverse dimensions of the RFQ are significantly larger than those in 4-vane high-frequency RFQs built using the brazing technique; b) due to the large cut-out in the vane it is prudent to demonstrate mechanical stability during high temperature brazing. Once the fabrication is complete, testing of the RFQ prototype over the wide range of input power is necessary. Successful testing of the RFQ over the wide range of RF power level will simplify the design and minimize the cost of the RIA Driver Front End because the same RFQ will be able to accelerate the full range of ions from proton to uranium.

Recently, we have performed tests of major brazed junctions of the RFQ engineering prototype that demonstrated machining and brazing of the copper vane assembly within specified tolerances. Fabrication of the full-power copper prototype of a single segment of the 57.5 MHz RFQ will be pursued as soon as funds become available..

HYBRID RFQ FOR THE POST-ACCELERATOR

The Hybrid Radio Frequency Quadrupole (H-RFQ) is an accelerating structure designed to accelerate low-velocity heavy ions with a q/A ratio = 1/240 [5]. The assembly drawing of the H-RFQ is shown in Fig. 3. The H-RFQ structure consists of three sections of drift tubes and two RFQ sections. In the drift tube sections the beam is accelerated and defocused transversely. Transverse focusing is provided by the RFQ sections. Each of the RFQ sections consists of two sets of non-modulated vanes with a length of $\beta\lambda$ separated by a drift space of $\beta\lambda/2$. The appropriate focusing strength is achieved by adjusting the distance between the vanes. Using the combination of the drift tube and RFQ structures a factor of two higher output beam energy is achieved when compared to a conventional RFQ accelerator.

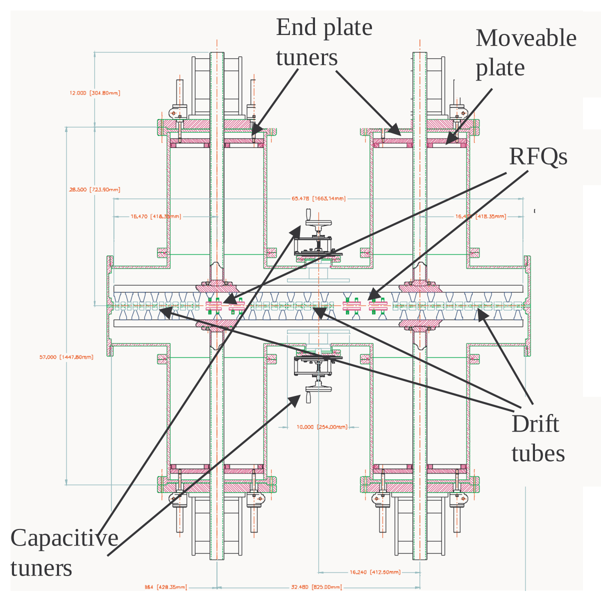

Figure 3. Assembly drawing of the H-RFQ cold model.

A half-scale (24.25 MHz) aluminum cold model of the Hybrid RFQ has been designed, built and tested. The goals were to determine the final resonator dimensions, accelerating and focusing field distribution, quality factor and coupling to the external power supply.

First, a numerical simulation of the cold model's electrodynamic parameters was done using the MWS code. The numerical simulation of this complicated structure had some difficulties. The size of the drift tube gaps and the RFQ vane spacing is very small compared to the overall dimensions of the cavity. This difference required a very large number of mesh cells for the simulation which resulted in unacceptable calculation time and the solution was non-convergent. To rectify this, some simplification of the shape of the structure had to be implemented. With this simplification a frequency error in the simulation was expected. Therefore, the designed resonator dimensions needed experimental testing and the aluminum cold model of the H-RFQ (Fig. 4) was built.

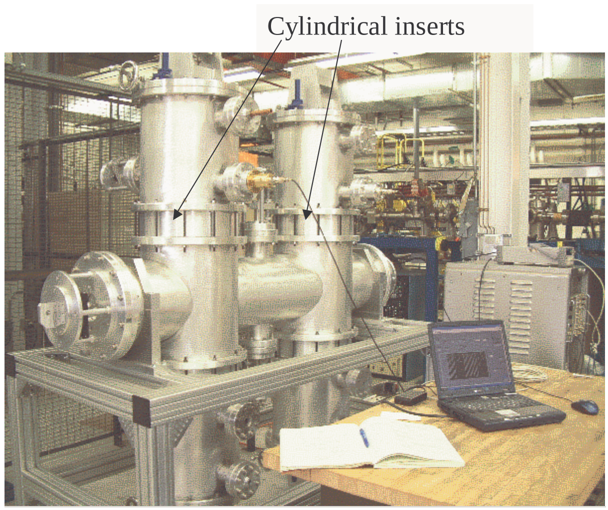

Figure 4. 24.25 MHz Hybrid RFQ aluminum cold model.

The experimental investigation of the 24.25 MHz H-RFQ cold model was carried out using both an HP Network Analyzer and a standard bead-pull technique using a phase-locked loop. The first measurements of the electrodynamics parameters of the cavity revealed three important shortcomings of the cold model. These are: the measured quality factor turned out to be 3.5 times lower than the calculated value, the frequency was approximately 2 MHz high, and there was a tilt in the field amplitude distribution of the third drift tube section.

To address the low Q, a stiffer spring material from Bal Seal Engineering was used to improve the RF contacts. In addition, we used special conductive silver grease supplied by Tecknit. After these modifications were made the measured quality factor was stable and was about 70% of the calculated value. Table 2 summarizes these results.

Table 2. H-RFQ electrodynamics parameters.

	MWS simulation	Measurement before the modification	Measurement after the modification
Q	4700	1350-2300	3150
f (MHz)	24.65	26.5	24.25

To improve the resonant frequency the dimensions of the H-RFQ model have been changed. Cylindrical inserts to lengthen the vertical stubs of the cavity were designed and installed to lower the eigen frequency (see Fig. 4). After this modification the resonant frequency was close to the expected value as is seen from Table 2.

To improve the final problem of the field tilt, capacitive tuners were installed at appropriate locations. These tuners removed the field tilt in the end of the third drift tube section. The final distribution of electric field along the structure is shown in Fig. 5. The amplitude of the field in the accelerating gaps is uniform within ±1.5% that is fully acceptable from the beam dynamics point of view [5].

The designed resonant frequency, uniform field amplitude distribution and high quality factor in the resonator were obtained after slight modifications of the model designed by the MWS code. Complete specifications for the final design of the 12 MHz hybrid RFQ have been established and detailed drawings of the full-power 12.125 MHz H-RFQ are being prepared.

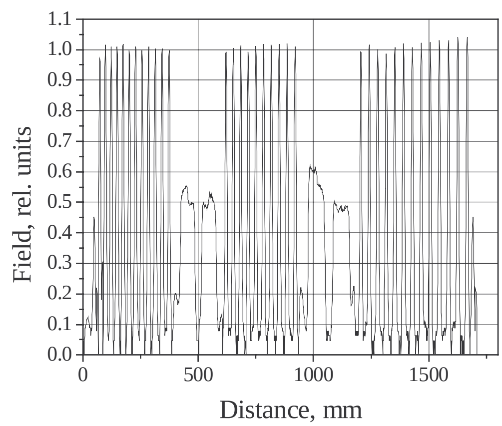

Figure 5. Field distribution along the H-RFQ.

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