PRELIMINARY DESIGN OF A 70MHZ RFQ FOR RARE ISOTOPE BEAMS*

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Abstract

A Radio Frequency Quadrupole (RFQ) is being designed for the acceleration of rare isotope beams from ECR ion sources or beam production system such as an isotope separation on line (ISOL) or an in-flight separation. For the case that we can't have enough beam currents from an ion source, we studied the simultaneous acceleration of multi charge states beams from an ion source. For the uranium beam, according to our code simulation, we found that a conventional RFQ can accelerator can accelerate up to three charge states from a single ion source.

INTRODUCTION

We are developing a Radio Frequency Quadrupole (RFQ) as a lower energy part for a 200-MeV/u heavy ion linear accelerator. The RFQ accelerates the 10-keV/u heavy ion beams from ion source (hydrogen molecules to uranium) and injects the 300-keV/u beam to the superconducting linac. Table 1 shows the basic parameters for the RFQ accelerator.

Table 1: Basic RFQ Parameters

A/q	≤ 7.5
Reference particle	$^{238}U^{33+}$
Beam current	8 pμA
Input energy	10 keV/u
Final Energy	300 keV/u
Duty	100% (CW)
Beam power	214 W

LEBT BEAM DYNAMICS

If an ion source can supply 8 pμA $^{238}U^{33+}$ beam, we can use a conventional LEBT (low energy beam transport) with two solenoids. But the state of art ion source is far short of delivering required 8 pμA $^{238}U^{33+}$ beam at the end of the linac. We need a way to increase accelerated beam current. Figure 1 shows the LEBT which consists of three parts and can match $^{238}U^{32+}$, $^{238}U^{33+}$ and $^{238}U^{34+}$ from an ion source to a RFQ.

The first is the matching section of the heavy ion beams extracted from an ion source to the beam selection system. It consists of four electrostatic quadrupoles. The second part is the beam selection system which includes two 90° degree bending magnets and two electrostatic triplets. The aperture for beam selection is located at the center between two bending magnets. The third part is for matching beams into RFQ. This part also consists of four electrostatic quadrupoles. Figure 2 shows the simulation result with TRANSPORT code.

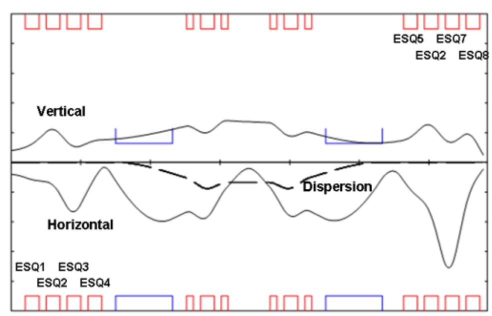

Figure 2: TRANSPORT result in the heavy ion LEBT: Dispersion function (dotted line) and beam envelop function both in horizontal and vertical directions.

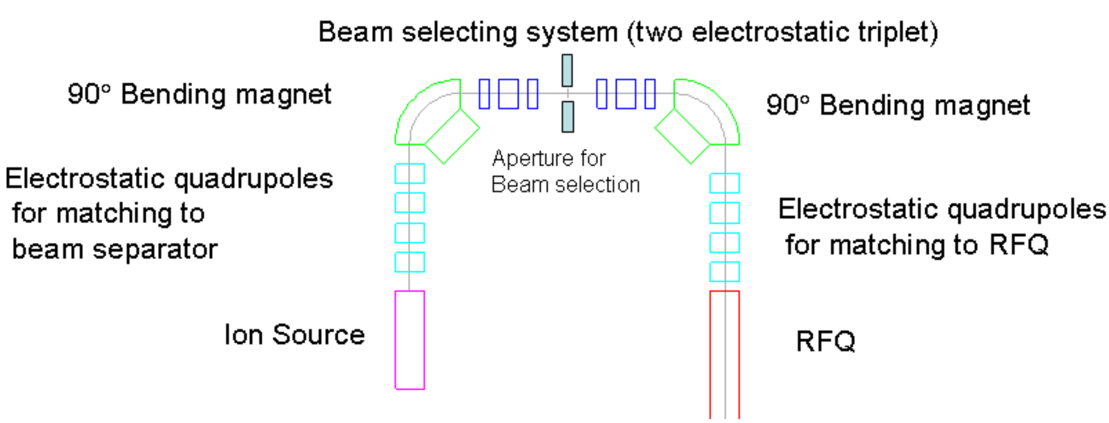

Figure 1: Layout of the heavy ion LEBT: It consists of two matching sections and a beam selecting system.

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RFQ BEAM DYNAMICS

For the rf frequency, we have chosen 70 MHz which is between the frequencies for Isotope Science Facility at Michigan State University (80.5 MHz) [1] and Advanced Exotic Beam Laboratory (AEBL) at Argonne National Laboratory (57.5 MHz) [2]. Table 2 shows the main design parameters.

Table 2: RFQ Design Parameters

RF frequency	70 MHz (λ = 4.3 m)
Beta	4.62e-3 ~ 2.53e-2
Kilpatrick	<1.6
Vane voltage	75 kV
Emittance	0.1πmm-mrad (nor. rms)

We used the PARMTEQM code [3] to create a RFQ structure with the parameters in Table 2 and to simulate the beam dynamics through the RFQ with the reference particle of $^{238}U^{33+}$. The number of macro particles is 30,000 and the beam current is 8 pμA for $^{238}U^{+33}$. The length of the RFQ is 4.958 m and the transmission rate is 94.3 %. Figure 3 shows the beam traces along the RFQ.

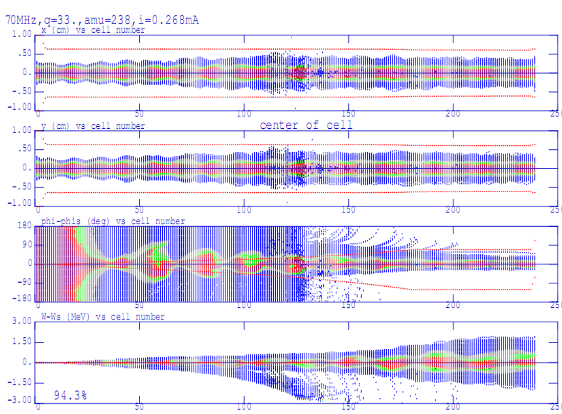


Figure 3: Uranium Beam Traces along Heavy Ion RFQ.

Figure 4 shows the beam at the exit of the RFQ in phase space. The full beam size is about 5-mm diameter and the energy spread is within ±3% which is tolerable for the downstream superconducting accelerator. We verified the acceleration of ions from hydrogen to uranium with the same structure and the lower vane voltage by simulations. The transmissions of lighter ions are generally better than uranium. Also we expect more current from an ion source than uranium. Thus for beam lighter than uranium, higher particle currents are expected than uranium.

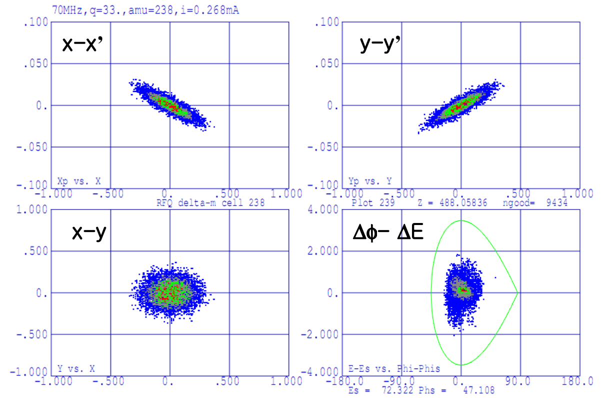


Figure 4: RFQ Output Uranium Beam in Phase Space.

For the simultaneous acceleration of the three charge state ($^{238}U^{32+}$, $^{238}U^{33+}$ and $^{238}U^{34+}$) from an ion source, we checked the transmission of the charge states in Table 3. For the every charge state, more than 85% can be transmitted and accelerated with separate code simulations. When the 8 pμA of the one charge state isn't available from an ion source, we can use up to three charge states to get enough current. The three charge states currents are expected to be almost same.

Table 3: Transmissions of Three Charge States

Charge State	Kinetic Energy	Transmission
32	2.308 MeV	86.8 %
33	2.380 MeV	94.3 %
34	2.452 MeV	91.3 %

Figure 5 shows the three charge states beam at a RF bucket. The three beams occupy the almost same phase space. As a result, the beams have the same beam properties. But if we plot the beam in the longitudinal direction in detail, as shown in Fig. 5 (a), we can find that there is 8.1 degree separation between the $^{238}U^{32+}$ and $^{238}U^{33+}$, but 0.3 degree between $^{238}U^{33+}$ and $^{238}U^{34+}$. 0.3 degree is negligible, but 8.1 degree can be a big number for the superconducting cavities in the downstream. All six dimensional information shall be used in following superconducting linac.

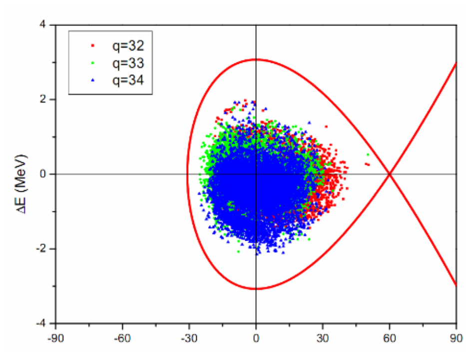
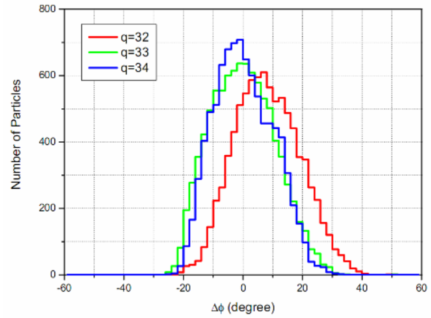
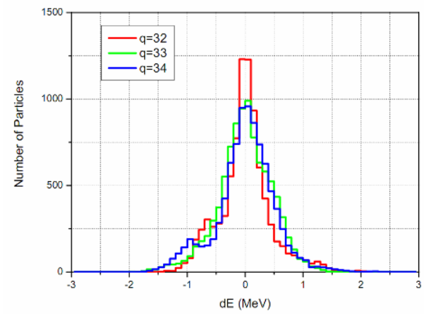


Figure 5: RF bucket with the three charge states



(a) in phase



(b) in energy

Figure 6: Beam profile in longitudinal direction for the three charge states.

RFQ RESONATOR

For the structure of a heavy ion RFQ, we can consider a four-vane-type structure, which is efficient for proton, a four-rod-type structure which is compact for heavy ions, and a four-vane-type structure with windows, which is an intermediate type of structure between a four-vane and a four-rod structure [3]. We choose the four-vane-type structure with windows, considering the cw operation, as shown in Figure 7.

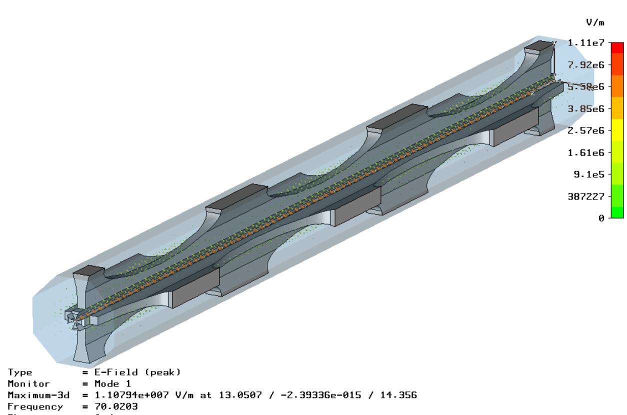


Figure 7: Electric field in RFQ resonator.

We designed the resonator with the MWS (Micro Wave Studio) code and tuned the resonance frequency by adjusting the sizes of the windows. Figure 7 shows the electric field patterns in the designed resonator. Table 4 shows the design parameters of the RFQ resonator. The frequency difference between the quadrupole mode and the nearest dipole mode is very important for stable operation. If we can't have enough frequency difference, we should use any mechanism, such as dipole stabilizers and pi mode stabilizers, to make a larger difference or to stabilize the dipole mode. In this design, we have an 8-MHz difference, which is sufficient for the stable operation.

Table 3: RFQ Resonator Design Parameters

Operating frequency [MHz]	70.0
Frequency of the nearest mode [MHz]	78.65
Q factor	8339
Total RF power losses [kW]	80.0
Kilpatric	1.47
Specific RF power losses [kW/m]	19.8

CONCLUSION

We studied the feasibility that a heavy ion RFQ can accelerate the three charge states ($^{238}U^{32+}$, $^{238}U^{33+}$ and $^{238}U^{34+}$) beams from an ion source. For the three charge states, more than 85% transmission is simulated and the beam properties are almost same. But we should check the effect due to the 8.1 degree phase separation between $^{238}U^{32+}$ and $^{238}U^{33+}$ in the superconducting accelerator in the downstream, and the energy acceptance of the accelerator.

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