DESIGN OF THE FRIB RFQ

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Abstract

The Facility for Rare Isotope Beams (FRIB) will provide a wide range of primary ion beams for nuclear physics research with rare isotope beams. The FRIB linac includes a room-temperature front end and a SRF linac capable of accelerating medium and heavy ion beams to energies beyond 200 MeV/u with a power of 400 kW on the fragmentation target. A 4-vane RFQ operating at 80.5 MHz at the front end of the linac accelerates heavy ion beams from 12 keV/u to 0.5 MeV/u, in CW mode. The design concept for the 4-vane RFQ is introduced and several important technical issues are discussed in this paper.

FRIB LINAC FRONT END CONGIGURATION

The FRIB Front End is designed to provide stable ion beams up to uranium with intensity sufficient to achieve 400 kW beam power on the FRIB target [1]. The FRIB Front End includes two ECR ion sources, two charge selection systems, LEBT, RFQ, and MEBT. To enhance availability and maintainability, the ECR sources and their charge selection systems are placed at the ground level in the support building about 10 m above the linac tunnel floor. The RFQ is located in the linac tunnel below. The beam transport is achromatic and designed to transport two charge states simultaneously with a normalized charge difference $\delta Q/Q$ of less than 4% to double intensity of heavy ion beams. The general arrangement of the Front End equipment is shown in Figure 1.
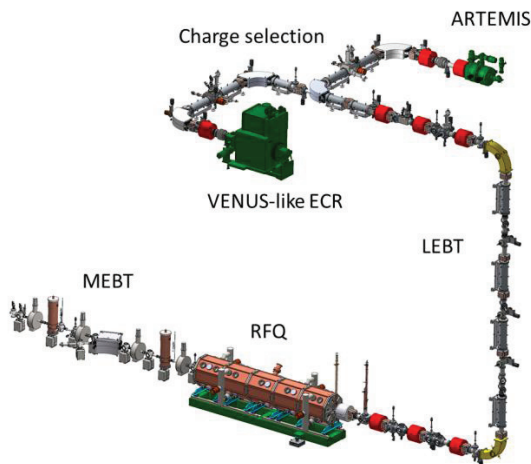

Figure 1: FRIB Front End Layout. Two ECR sources are located at the ground level. The RFQ and MEBT are located in the linac tunnel 10 m below grade.

DESIGN PARAMETERS OF THE RFQ

The FRIB RFQ utilizes a 4-vane structure to accelerate stable ions with charge states Q/A between 1/7 and 1/3 from 12 to 500 keV/u with an estimated transmission efficiency of approximately 80%. Table 1 shows the main RFQ parameters.

Table 1: FRIB RFQ Design Parameters. RF Parameters obtained in CST Microwave Studio Simulations

Frequency (MHz)	80.5
Injection/Output energy (keV/u)	12/500
Beam current (typical, μA)	450
Beam emittance (full, norm, πμm)	1.0
Long. Emittance (99.9%, keV/u-ns)	1.5
Transmission efficiency (typical, %)	80
Design charge-to-mass ratio	1/7-1/3
Accelerating voltage ramp (U, kV)	60 – 112
Surface electric field (Kilpatrick)	1.6
Quality factor	16500
Operational RF power (kW, O-U)	15 – 100
Length (m)	5.04

The RFQ beam physics design is optimized to minimize the longitudinal emittance of the accelerated beam ([2][3]). To eliminate longitudinal distribution tails and form a small longitudinal beam emittance the longitudinal acceptance of the RFQ is kept small and almost constant at the low energy part of the RFQ. DC beam produced by the ECR ion sources is bunched and matched to the RFQ acceptance using an external 3-harmonic buncher [1]. This approach allows using an additional low power RF resonator between the buncher and the RFQ to remove the energy spread of two charge state beams to achieve a small emittance.

A 4-vane structure was selected for the RFQ. Numerical tools required to design these types of structures are well established and simple to use [4]. To increase the RFQ output energy a linear accelerating voltage ramp is implemented. The linear voltage ramp is accomplished through proper sizing of the vane undercuts, providing local frequency perturbations at both ends of the structure. Figure 2 shows evolution of structure parameters along the RFQ length. Dipole mode suppression rods attached to the structure endplates are

utilized to move dipole mode frequencies away from the accelerating mode frequency. The quadrupole and dipole mode local perturbations are fine-tuned during construction using 27 fixed mechanical slug tuners distributed along the length of the machine.
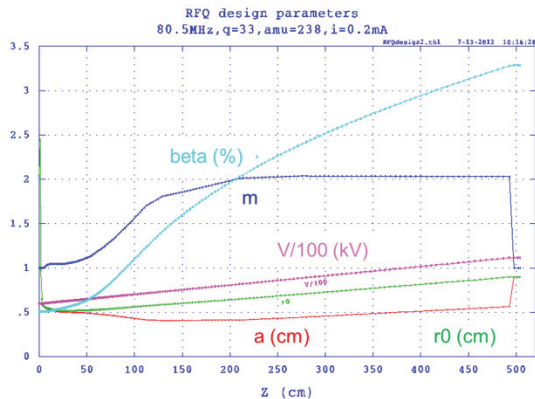

Figure 2: RFQ structure parameters as a function of the longitudinal coordinate (PARMTEQ notations).

A full 3D model of the RFQ, including undercuts, stabling rods, and the slug tuners, was implemented in the CST Microwave Studio (MWS) [5] to accurately tune required parameters and simulate fields and surface losses. The difference between the design and simulated voltage profiles was less than 1%. The length of stabilizing rods was adjusted to detune closest dipole modes equidistantly from the accelerating mode. In adjusting the length of the rods, the frequency of monopole-like parasitic modes located in the end regions of the RFQ structure was also monitored. The resulting frequency of the closest dipole modes was 78.3 and 83.2 MHz. The frequency of the monopole modes was 76.1 and 83.0 MHz for the higher and lower energy end modes respectively.

RF power will be coupled to the RFQ through a single coaxial loop coupler. Preliminary engineering studies and multipacting simulations did not reveal outstanding issues with the coupler concept.

RFQ MECHANICAL DESIGN

A major vane-minor vane construction approach is planned where the cross-section of the structure is constructed of four machined components joined in an assembly brazing operation performed across four interface surfaces that are all flat and parallel. To manage the weight of the structure for machining, the structure is divided into five longitudinal sections (segments) each roughly one-meter in length. The actual position of the longitudinal joints are placed at cell boundaries to allow easier determination of the machining reference location with respect to the vane machining blank ends and to ease inspection following machining of the vane contours.

Ports for slug tuners and vacuum pumping are uniformly distributed along the entire structure in each of the four quadrants. One of the slug tuner ports in the center segment at the geometric center of the structure

will be used to mount the single coaxial loop drive coupler. The drive coupler is a 50-ohm matched impedance magnetic field coupler utilizing a ceramic disc vacuum window for vacuum isolation of the RFQ from the dive line. The coupler and ceramic window are only moderately thermally loaded from the 100 kW peak drive power. A standard 6-1/8 inch diameter coaxial transmission line will connect the drive loop to the RF power amplifier located in the equipment building above the accelerator tunnel. An assembly view of the RFQ design model and its support stand is shown in Figure 3.
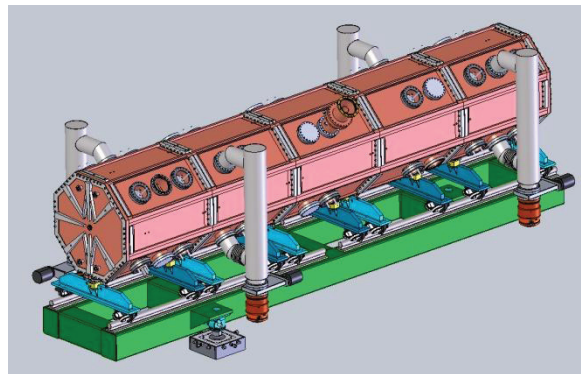

Figure 3: RFQ full assembly model including the drive coupler with vacuum headers and support structure.

Vacuum Port and Slug Tuner Configuration

The structure is fitted with a total of 27 slug tuner ports and 20 vacuum ports. Calculations indicate that only 8 of the vacuum ports will require active pumping to maintain the desired 5.0e-8 torr operating pressure after the structure is fully rf conditioned. Initially the structure will be fitted with turbomolecular pumps for rf conditioning in the off-line test bay. Later, after the structure has been relocated to the accelerator tunnel, the pumps attached to the main manifolds will be replaced with ion pumps for long-term service. Additional pumping is available directly mounting to the RFQ structure if required during conditioning. The vacuum ports utilize standard rf grating.

The slug tuners are actively water cooled but the vacuum grating does not require special cooling directly in the rf attenuation grate as the peak power dissipation is less than 0.3 W/cm^2 in the outer quadrant region of the cavity.

Cavity Endplates and Tuners

Due to the large diameter of the structure, additional mechanical stiffening using stainless steel ribs is required on the copper endplates. The adopted design uses cooling channels between the ribs and the plate to provide stiffening while supplying the water cooling across the endplates and to the dipole stabilizer rods that are fastened to the inside surface of the endplate. The stabilizer rods are double-wall copper tubing with active water cooling. The total heat load on the stabilize rods is less than a kilowatt on each endplate but the extended length of the surface is too long to transfer the heat purely

through conduction. Figure 4 shows a view of the inside surface of the upstream endplate. The length and radial position of the stabilizer rods was determined with the 3d CST Microwave Studio analysis mentioned previously. The access ports for field measurement during tuning can be seen in the upper and lower regions of the plate surface.
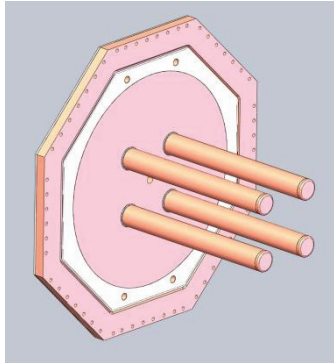

Figure 4: Dipole stabilizing rods and endplate as a brazed assembly.

A cross-section view of the slugtuner is shown in Figure 5 with the water cooling brazed cover plate shown. Each slug tuner is actively cooled due to their extended surfaces in the high magnetic field region.
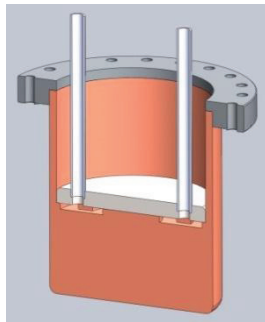

Figure 5: Section view of a slug tuner body.

The mounting flanges on the RFQ body and the tuners themselves are direct stainless steel to copper furnace-brazed subassemblies utilizing 8-inch knife-edge seal flanges. Preparation in this way allows verification that the first stainless-to-copper braze assembly is vacuum tight before proceeding to join the assembly to the main body.

Segment Assembly and Support Stand

The diameter of the structure at about 94 cm and we decided not to attempt to place complete diametral rings at the joining flanges so as to avoid difficulty with thermal expansion mismatch problems in obtaining a good vacuum-tight braze joint between the flange and the body of the RFQ. This has been problematic for some other recent designs and we decided to use the alternate approach of attaching stainless steel segmented bars along the edges of the straight sides of the other body. The bars are shaped like a thick angle section with one edge inset

into the body slightly to allow proper stiff clamping of the vacuum seal between two rigid bars with the copper body of the segment end sandwiched between. A stiff flange arrangement results that avoids the large thermal strain mismatch encountered with continuous rings in brazing. Figure 6 shows a view of segment-1 with the low energy endplate removed. The major vanes are located in the horizontal plane. The angled vane undercuts, the stainless flange bars, and the general size and shape of the vane end undercuts are visible. Also visible is the vacuum seal groove around the perimeter of the end surface. The outline of the copper plugs that cover the drilled longitudinal water passages in the body of the vane are also visible just outside the seal groove. There is a shallow pocket machined on the back sides of the vanes to allow placement of the end flange clamping bars and to reduce weight of the structure.
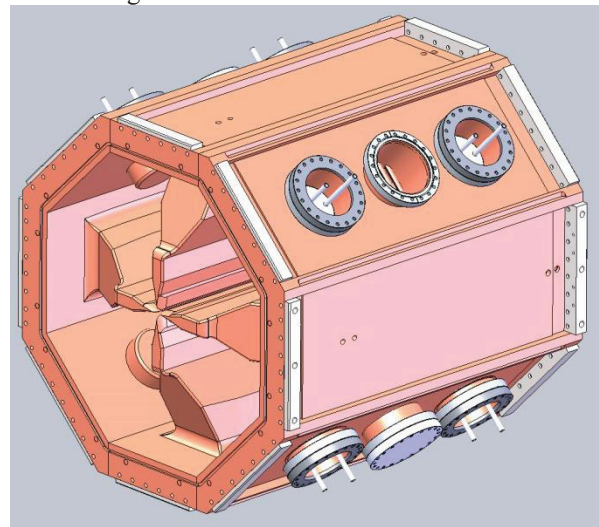

Figure 6: Segment 1 assembly showing the vane arrangement and tuner and vacuum port placement.

REFERENCES

[1] E. Pozdeyev, et al, LINAC 2012, p. 1047.
[2] P. Ostroumov, et al, Phys. Rev. ST Accel. Beams 5, 060101 (2002).
[3] Q. Zhao, et al, LINAC 2004, Lübeck, Germany, p. 599.
[4] K. Crandall, et, al, PARMTEQ-A beam-dynamics code for the RFQ linear accelerator.
[5] CST Microwave Studio, v.12, CST GmbH (Darmstadt, Germany), 2012. www.cst-world.com