# Design of an 80-MHz RFQ Linac for Heavy Ions

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*Abstract*

At the Tokyo Institute of Technology (TIT) a four-vane RFQ is to be applied for inertial confinement fusion research[1]. The RFQ (TIT RFQ) is designed for acceleration of particles with charge to mass ratio (q/A) of 1/16 from 5keV/amu to 213keV/amu. The planned maximum injection beam current is 10mA for $^{16}O^{+}$. Beam dynamics was calculated using a PIC (Particle-In-Cell) code which can take influence of the multipole components in the intervane potential into account. For input beam current of 10mA transmission of 60% was obtained.

A half-scaled cold model was fabricated to investigate fundamental rf characteristics. In the cold model experiment, the difference in electric field strength between each quadrant was minimized to ±3% by using side tuners and flat field distribution along the beam axis was achieved by adjusting end tuners.

## I. INTRODUCTION

In a previous paper[1] a design of the TIT RFQ with the vane-tip curvature radius of $0.75r_0$ was presented. The computer code PARMTEQ was used to simulate the beam dynamics in the RFQ and the computer code GENRFQ was used to generate the vane parameters for PARMTEQ calculation. For this old design the beam transmission was expected to be 72% for the injection current of 10mA.

In the meantime, one of the authors of this paper developed a new simulation code "QLASSI (Quadrupole Linear Acceleration Simulator with Space and Image charge effect)"[2] which can simulate the beam dynamics including influence of the multipole components in the intervane potential. This code was applied to calculation of the beam dynamics for the old design. Since the result of this calculation showed very poor transmission efficiency of 34%, the TIT RFQ had to be redesigned.

In this paper we describe the modifications of vane-tip design as well as the cavity geometry, which are necessary to improve the beam dynamical performance. The beam transmission performance for the new design is presented. Recent results on a half-scaled model including development of tuning device are also reported.

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## II. NEW SIMULATION CODE QLASSI

In computer code QLASSI, the equation of motion in the RFQ is expressed as

$$\frac{d^2\mathbf{r}}{dt^2} = q\mathbf{E}/m = -(q/m)\nabla(U_{rfq}+U_{sc}+U_{ic}), \quad ...(1)$$

where $U_{rfq}$, $U_{sc}$ and $U_{ic}$ are the external RFQ potential, the space charge potential and the image charge potential, respectively. In the calculation, eq.(1) is numerically integrated for each particle using fourth-order Runge-Kutta method. Harmonics up to the dodecapole moment are taken into account in $U_{rfq}$. $U_{sc}$ is given by the sum of monopole Coulomb potential from all other particles. $U_{ic}$ is determined by solving a 3D Dirichlet's boundary problem defined by the beam space charge and the metallic electrode surface.

Figure 1 shows axial transmission profile calculated using QLASSI for the old design. For the injection beam current of 10mA the transmission is only 34%, which is less than half of the one calculated using PARMTEQ.

## III. NEW DESIGN OF THE TIT RFQ

The TIT RFQ was redesigned since the predicted transmission was limited to 34%. In the new design the curvature radius of vane-tip was increased from $0.75r_0$ to $r_0$ in order to suppress the multipole components. Parameters of the new design are summarized in Table 1. In order to increase rf focusing effect $r_0$ was decreased from 0.495cm to 0.466cm. The vane length becomes 20cm longer than that of the old design owing to the reduction of $r_0$. The total vane length is 422cm which corresponds to 273 cells including a radial matching section with 20 cells. Figure 2 shows axial transmission profile calculated using QLASSI for injection current of 10mA. The transmission is improved up to 60%.

The cavity geometry was determined using computer code SUPERFISH. Main rf parameters are summarized in Table 2. The operating frequency is 80MHz which is same as that of the old design. The cavity diameter was decreased from 76.6cm to 72.5cm in order to keep a resonant frequency to be 80MHz. The wall loss increased

Table 1
Design Parameters of TIT RFQ

| | |
|---|---|
| Charge-to-mass ratio | ≥1/16 |
| Operating frequency (MHz) | 80 |
| Input energy (keV/amu) | 5 |
| Output energy (keV/amu) | 213 |
| Normalized acceptance (cm·mrad) | 0.05π |
| Vane length (cm) | 422 |
| Total number of cells | 273 |
| Characteristic bore radius, $r_0$ (cm) | 0.466 |
| Minimum bore radius (cm) | 0.294 |
| Margin of bore radius, $a_{min}/a_{beam}$ | 1.1 |
| Maximum modulation, $m_{max}$ | 2.05 |
| Focusing strength, $b$ | 3.4 |
| Maximum defocusing strength, $\Delta_b$ | -0.051 |
| Synchronous phase, $\phi_s$ (deg.) | -90 → -20 |
| Intervane voltage (kV) | 79 |
| Maximum field (Kilpat.) | 2.2 |
| Transmission (%) | (0mA input) 87 |
| | (10mA input) 60 |

Table 2
Main rf parameters of TIT RFQ

| | |
|---|---|
| Resonant frequency (MHz) | 80 |
| Calculated Q value | 20000 |
| Wall loss (at nominal intervane voltage, kW) | 89 |
| Shunt impedance (MΩ/m) | 29.5 |
| Calculated maximum field (Kilpat.) | 2.2 |
| Vane-tip radius (cm) | 0.466 |
| Cavity diameter (cm) | 72.5 |
| Cavity length (cm) | 440 |

from 81kW to 89kW.

The structure of the TIT RFQ is illustrated in Figure 3. Each quadrant of the cavity has six plunger-type tuners, only one of which is movable because other five plungers are fixed after adjustment. End regions consist of inductive end cuts and a capacitive tuner like a pan (called an end cap hereafter). Since it is impossible to machine the 4m long vane with sufficient accuracy, three tanks with 1.4m long vanes are connected in series.

## IV. COLD MODEL TEST

A cold model without vane modulation and a radial matching section was fabricated. The tank length and the tank diameter are 1.7m and 32cm respectively. Each quadrant has six plunger-type side tuners to obtain the quadrupole mode. Two kinds of capacitive tuners, plunger-type end tuners and an end cap, were equipped on each end plate and dimensions of these tuners were tested.

Although alignment of four vanes was carried out using two end jigs and reamer pins, setting accuracy was too poor to observe the quadrupole mode. Re-alignment using a pin-gauge achieved the gap difference between vanes within 30μm along the whole vane length. The quadrupole mode could be excited after this re-alignment but the measured electric field strength of this mode was quite different in each quadrant.

The side tuners were adjusted in order to make the electric field strength equal in each quadrant. The electric field near the beam axis was measured with the bead-perturbation method. The resonant frequency of quadrupole mode is 192.0MHz and the frequency shift due to the bead-perturbation is shown in Figure 4. This result shows that the difference in electric field strength between each quadrant is within ±3%. It is possible to make the difference smaller by repeating the fine side tuner adjustment.

Flat electric field distribution along the beam axis is achieved by using the end caps illustrated in Figure 5. One end cap faces the side of four vanes and the capacity of end region becomes much higher than that of the plunger-type tuner, because the facing area is much larger.

The flatness $F$ is defined as

$$F = \frac{\hat{E}_{end}}{E_{cent}}, \qquad ...(2)$$

where $E_{cent}$ is the electric field strength at center and $\hat{E}_{end}$ is the mean electric field strength of both ends, respectively. In Figure 4, the distance between end cap and vanes is 5.4mm and the flatness $F$ is 0.97. If the end tuners were adopted, the gap between end tuner and vane would be only 1.5mm in order to obtain the same $F$. It is clear from this result that the end cap is preferable to avoid an electric discharge and concentration of wall loss in the end region.

## V. SUMMARY

Since the transmission performance calculated using QLASSI was very small, the TIT RFQ was redesigned. In the new design the curvature radius of vane-tip was determined to be $r_0$ in order to suppress the multipole components. The characteristic bore radius $r_0$ was decreased to 0.466cm in order to increase rf focusing effect. Due to these modifications, the beam transmission recovered to 60%.

The cavity dimensions were also redesigned to maintain the resonant frequency to be 80MHz. Owing to this change, the power dissipation increased by a factor of 10%.

A half-scaled cold model was fabricated without vane modulation and a radial maching section. In the cold model experiments, the difference in electric field strength between each quadrant was minimized to ±3% and the flatness of the field distribution along the beam axis was 0.97. In addition, useful results on the vane cutting method were acquired and applied to the design work of the actual cavity.

## VI. REFERENCE


[1] O. Takeda et.al., "Design Study on an 80MHz RFQ Linac for Heavy Ion", Proc. European Particle Accelerator Conf., Berlin, March 1992, 1334-1336

[2] Y. Oguri et.al., "Beam Tracking in an RFQ Linac with Small Vane-Tip Curvature", J. Nucl. Sci. And Tech., to be published


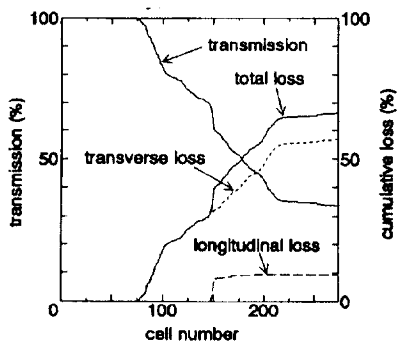


Figure 1 Axial beam transmission profile calculated using QLASSI for the old design (Injection current is 10mA)

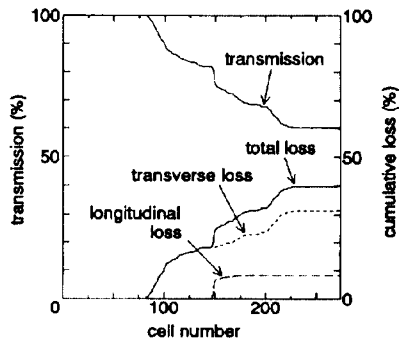


Figure 2 Axial beam transmission profile calculated using QLASSI for the new design (Injection current is 10mA)

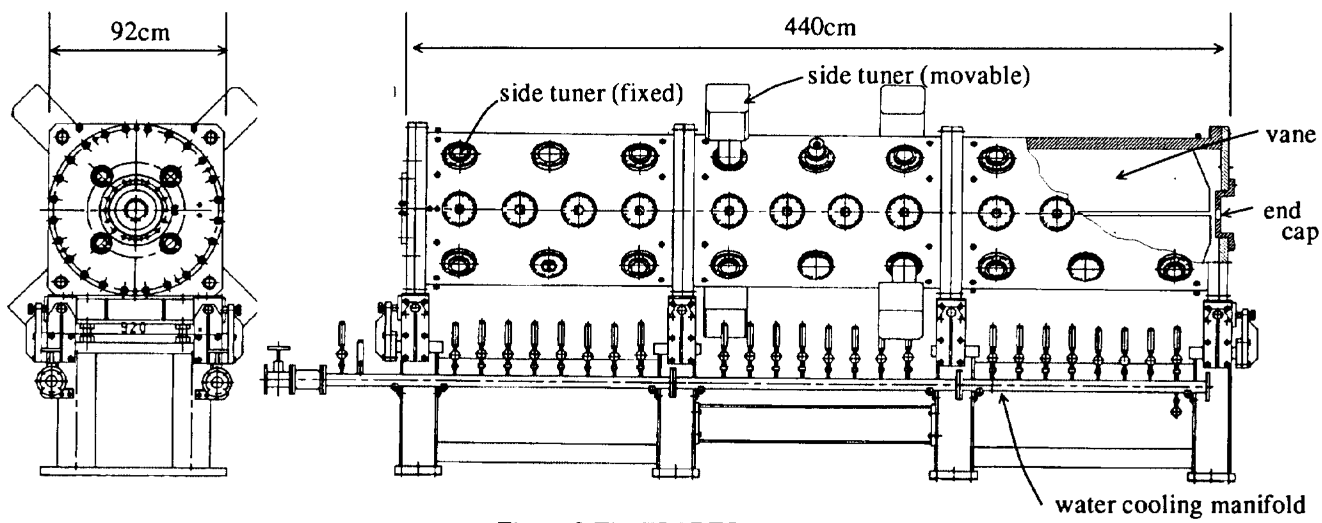


Figure 3 The TIT RFQ

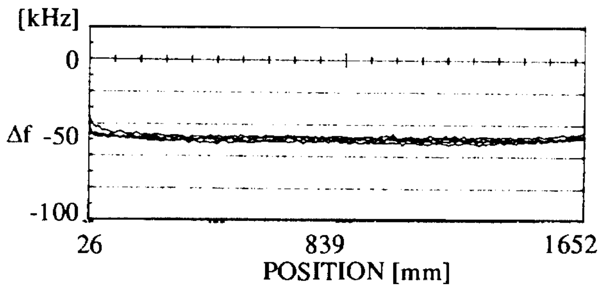


Figure 4 Frequency shift due to bead-perturbation

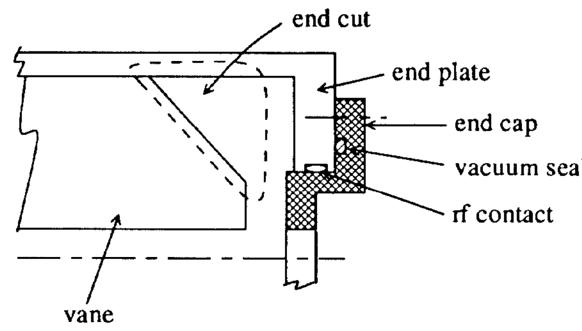


Figure 5 Schematic drawing of the end cap