PRAMANA
— journal of
physics

Vol. 59, No. 6
December 2002
pp. 957–962

The design of a radio frequency quadrupole LINAC for the RIB project at VECC Kolkata

V BANERJEE[1,*], ALOK CHAKRABARTI[1], ARUP BANDYOPADHYAY[1], T K BHAUMIK[1], M MONDAL[1], T K CHAKRABORTY[1], H PANDE[1], O KAMIGAITO[2], A GOTO[2] and Y YANO[2]
[1]Variable Energy Cyclotron Centre, 1/AF, Bidhan Nagar, Kolkata 700 064, India
[2]The Institute of Physical and Chemical Research (RIKEN), Hirosawa 2-1, Saitama 351-0198, Japan
*Email: vaishali@veccal.ernet.in

Abstract. A radio frequency quadrupole LINAC has been designed for the VECC-RIB project for an input beam energy of 1.0 keV/u and $q/A \geq 1/16$. The output energy will be about 90 keV/u for a 3.4 m long, 35 MHz structure. A half-scale cold model of the RFQ has been fabricated and tested for rf structure design study. The beam dynamics and rf-structure design along with the results of the cold model tests will be presented.

Keywords. Radio frequency quadrupole; beam dynamics.

PACS No. 229.17.+w

1. Introduction

An ISOL-post accelerator type of radioactive ion beam (RIB) facility is being built at VECC, Calcutta [1]. Radioactive nuclei produced inside a thick target using the proton and α-particle beams from the variable energy cyclotron at VECC will be transported to an on-line ECRIS where $q > 1^+$ RI beams will be produced. The desired RI beam with an energy of 1.0 keV/u and $q/A = 1/16$ will be separated in the low energy beam transport line after the ECRIS and accelerated to about 90.0 keV/u in a heavy-ion radio frequency quadrupole (RFQ) LINAC. Subsequently, the RI beams will be accelerated from 90.0 keV/u to the desired final energy using heavy-ion IH LINAC [2].

RFQ is considered to be the most suitable linear accelerator for acceleration, bunching and focusing of low energy beams with low q/A. For the acceleration of heavy-ion beams with low-β the RFQ structure chosen is a four-rod (extended vane) type resonating at a frequency of 35 MHz. The design specifications of the RFQ LINAC system are listed in table 1.

2. rf-Structure and beam dynamics design

The schematic lay out of the RFQ cavity-1 is shown in figure 1. The 3.4 m RFQ consists of two cavities. The resonant structure is formed by four vanes supported on eight posts on

Table 1. The design specifications of the RFQ LINAC for the VEC-RIB facility.

Input beam parameters	
Ion-source	6.4 GHz ECRIS
Extraction voltage	16 kV maximum
Energy and q/A	1 keV/u for $q/A = 1/16$
RFQ basic parameters	
Type	4-rod (extended vane type)
Frequency	35 MHz
Cavity dimensions	Rectangular cavity; $600 \times 560\text{mm}^2$
Vane length	3416 mm
Energy and q/A	80 keV/u for $q/A = 1/16$
Acceptance (design)	34 π·cm·mrad

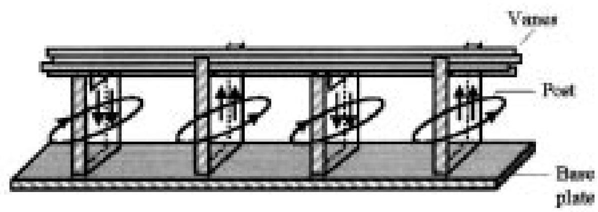

Figure 1. The schematic lay out of the four-rod RFQ LINAC. The direction of the magnetic flux density around the posts and the surface current is also indicated.

a base plate. Each diagonally opposite pair of vanes is supported by two posts. The basic rf cell of the above 'four-rod' structure can be described as two coupled $\lambda/4$ transmission lines excited in transverse π mode forming a parallel LC resonant circuit with the vanes as capacitance and the posts as inductance. Using this description the preliminary rf structure was fixed and further optimization was done with the code MAFIA. The Q value and shunt impedance of the 3.4 m long structure comes out to be about 9100 and 70 kΩ respectively.

The beam dynamics design of the RFQ was initially done for an input dc beam of $q/A \geq 1/16$ and energy 1.0 keV/u. The output energy for a length of about 3.4 m comes out equal to 80.0 keV/u with a transmission of 96.6% for a beam current of less than 1 mA and a vane voltage of 49.5 kV. The energy width of the output beam is $\pm 1.7\%$ for the above design. Instead of a dc beam, if a bunched beam is injected into the RFQ, one can obtain an output beam with a much narrower energy and phase width. Moreover, the machining of the RFQ vanes also becomes easier and cheaper. With this in mind we have modified the design of the RFQ for an external sinusoidal, single-gap pre-buncher. The RFQ accepts bunched beam of phase width of ± 42 degree and has a very short bunching section. With this configuration an output energy of 92.5 keV/u for the same length and vane voltage of the RFQ with an overall maximum transmission efficiency of 84% is calculated for less than 1 mA beam current. A list of detailed design parameters of the RFQ is given in table 2. The variation of the main beam dynamics parameters of the RFQ along the length (cell number) is shown in figure 2 and the simulated phase and energy distribution at the RFQ end is shown in figure 3.

Table 2. Main parameters for VECC RFQ.

Parameter	Modified RFQ for input bunched beam
Charge to mass ratio q/A	1/16
Operating frequency	35 MHz
Input energy (keV/u)	1.0 keV/u
Output energy (keV/u)	92.7 keV/u
(for the) Length of vanes	337.75 cm
Synchronous phase	-90 to -30
Total number of cells	148
Characteristic bore radius r	7.1 mm
Minimum bore radius a_{min}	4.01 mm
Maximum modulation m_{max}	2.331
Focusing strength B	4.83
Maximum defocusing strength D_{rf}	-0.085
Inter-vane voltage	49.5 kV
Kilpatrick factor	1.2
Transmission (0 mA)	74% or 84%
For buncher voltage	of 40 V and 78 V
Minimum energy width $\Delta E/E$ in %	$\pm$ 0.37 %

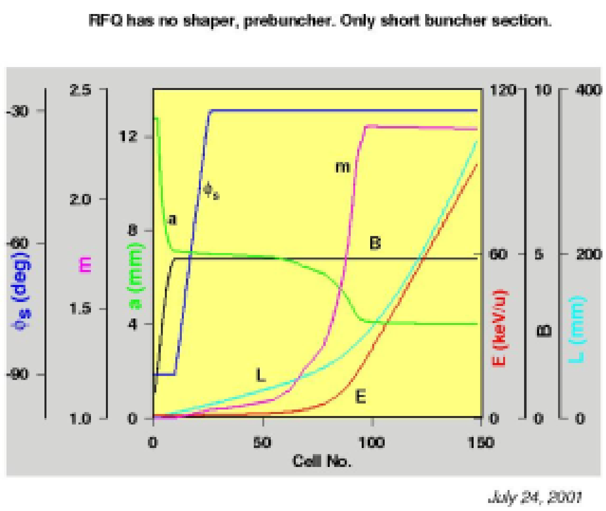

Figure 2. The variation of beam dynamics parameters along the length of the RFQ vane.

3. Mechanical design

Important mechanical considerations for RFQ are briefly discussed below. The vanes have to be machined in a three-dimensional milling machine according to the vane profile calculated using PARMTEQ under the conditions of stability of transverse and longitudinal

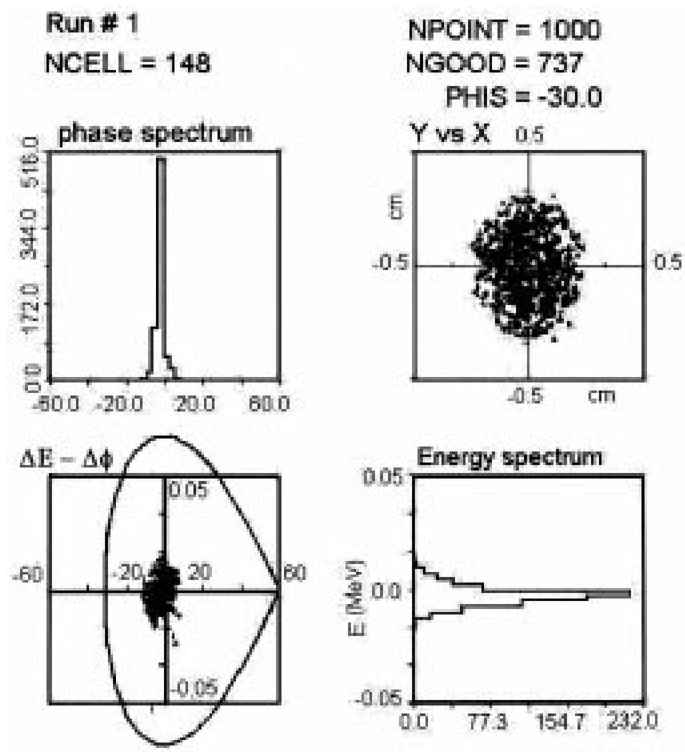

Figure 3. The phase and energy distribution at the end of the RFQ for the external buncher at 40 V.

motion. The characteristic radius of the RFQ is 7.1 mm with the minimum aperture radius coming down to about 4.0 mm in the acceleration section. Thus it is vital that the four vanes be machined and aligned to an accuracy of better than 50 micron for good transmission efficiency. In order to optimize and critically examine the complications in the fabrication process, sample vanes with three-dimensional modulated profile have been fabricated at CMERI Durgapur. The accuracy of machining and the surface finish obtained is within the acceptable limits. Also, special and accurate jigs and fixtures have been designed to achieve an accurate alignment of the vanes.

The other important and critical aspect is the cooling of the RFQ structure. The power loss density distribution in a post calculated from MAFIA is shown in figure 4. The cooling channel layout has been chosen keeping in mind the critical hot spots, especially at the vane to post and post to base-plate joints. The cooling calculation has been done for cavity-1 considering a total power dissipation of 20 kW which is about 2.0 times the designed value. The maximum temperature rise is limited to 5°C. This problem of steady state heat conduction with convective boundary condition has been solved using FEM code NISA and is described in detail in ref. [3].

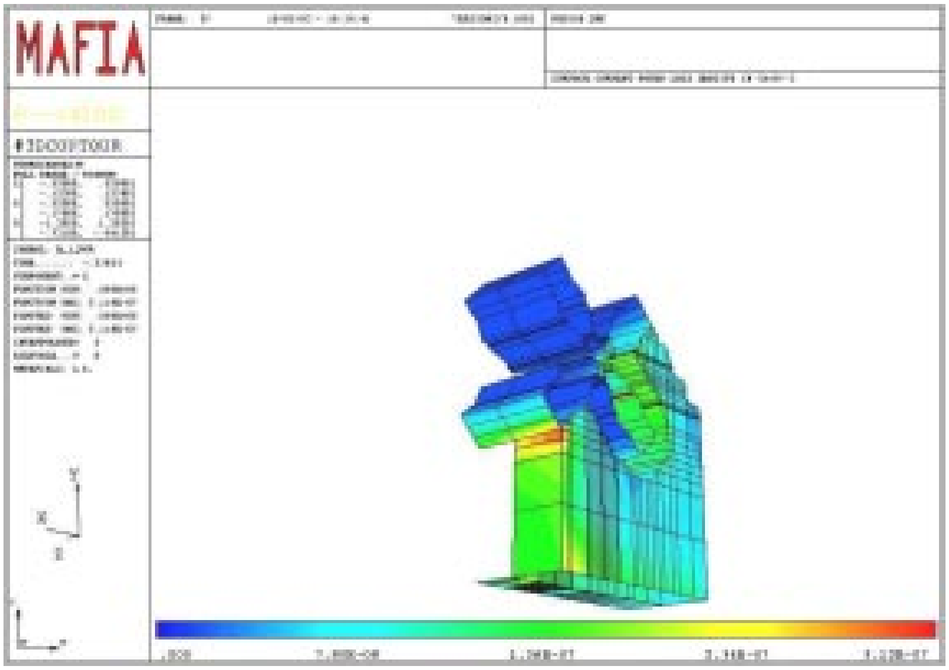

Figure 4. The calculated power loss density distribution in the RFQ post – the highest power loss density is indicated in red. It can be noted that the post-vane and post-base plate joints are the hottest spots and one needs to ensure adequate cooling at these points.

4. Cold model tests

The half-scale model of the 1.7 m RFQ (cavity-1) has been installed at the RIB laboratory. rf-Structure measurements have been done using a Network Analyser (model 8753E). The resonance frequency is measured to be of 73.66 MHz. The Q value measured using two pick-up loops under more than 94% reflection of power (−50 db) is close to about 3000. The resonance frequency decreases to about 73.4 MHz, if the loop coupler is placed in position. With the height of the posts increased by 12 mm, the resonance frequency shifts to 70.3 MHz.

The shunt impedance R_p was measured by the capacitance method [4]. The R_p value comes out to be 52.5 kΩ. The measured Q and R_p values are about 50% of the values calculated from MAFIA. The measured resonance frequency is also about 7% more than the calculated value. From the 'bead-pull' method, we have verified that the inter-vane voltage remains more or less constant by moving a teflon cylinder along the beam axis and observing frequency shift for each position. The frequency shift remained almost exactly the same as the cylinder is moved to different positions. By putting a long nylon thread, one by one in each quadrant, it is observed that the frequency shift is the same in all quadrants. This shows that the quadrupolar symmetry is achieved.

5. RFQ full scale cavity fabrication

The RFQ cold model tests have shown that the rf structure is close to the one designed. The vacuum tests of the cold model with the water cooling of the vanes and the posts is now underway. The design of the full scale cavity can be finalized after the successful completion of these tests and the fabrication started.

References

[1] A Chakrabarti, The radioactive ion beam project at VECC Kolkata – A status report, present citation
[2] Arup Bandyopadhyay, Post-accelerator LINAC design for the VECC RIB project, present citation
[3] M Mondal, *Proc. DAE Symp. on Nucl. Phys.* **B44**, 416 (2001)
[4] H Fujisawa, *Nucl. Instrum. Methods* **A345**, 23 (1994)