HEAVY ION RADIO-FREQUENCY QUADRUPOLE LINAC FOR VEC-RIB FACILITY

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Abstract

Post acceleration of ion beams would be done in Radio Frequency Quadrupole (RFQ) LINAC for the upcoming Radioactive Ion Beam (RIB) facility at Variable Energy Cyclotron Centre (VECC), India. A 33.7 Mhz RFQ capable of accelerating stable as well as RI beams of q/A≥1/16 to about 30 keV/u has already been constructed and operational since September 2005. This has been installed in a dedicated beam line for doing material science experiments. Another 3.4 m long RFQ resonating at 37.8 Mhz and capable of accelerating heavy ion beams upto 98 keV/u have been fabricated which is to be installed in the beam-line for the VEC-RIB facility. The physical parameters, rf test along with the measurements of accelerated beams from RFQ would be presented.

DESIGN OF RFQ

We plan to accelerate beams with mass ranging up to A=150 in the VEC-RIB facility[1]. The radioactive atoms would be ionized in Electron Cyclotron resonance ion source(ECRIS) operating in "High B-mode". The ions would be then subsequently mass separated and accelerated in RFQ and Linac tanks[2]. ECRIS in principle would be able to deliver beams of around 15^+ for uranium even in the on-line mode .Thus q/A≥ 1/14 seems to be a judicious choice for our RFQ. Normalized emmittance of ion beam has been taken to be 0.05 π cm mrad. Characteristic radius of 0.71 mm for the RFQ ensured a good transmission of the RI beams through the RFQ. The four-rod type structure have extended vanes supported on posts similar to the structure developed by Fujisawa[3]. The rods are placed at an angle of 45^o with respect to conventional horizontal and vertical axes.

The beam dynamics simulation has been done using GENRFQ and PARMTEQ code. Optimization of different physical parameters was done keeping in mind the goal to achieve the desired acceleration with minimum vane length and maximum transmission efficiency. Initially the RFQ was decided to design for input beam of energy of 1keV/u and input bunch width of $\pm 42^o$ and final energy of 86 keV/u[4]. The RFQ was designed to resonate at frequency of 35 MHz. A half scale cold model was fabricated for RF measurements. The results show good agreement with the simulation using MAFIA. In the next stage we have designed and fabricated 33.7 MHz RFQ delivering beam of 29 keV/u to be installed in the dedicated beam line for material science experiments . As the first post accelerator, using the experience and expertise gathered with 33.7 MHz RFQ final 3.4 m RFQ accelerating RIB's to 98 keV/u have been fabricated.

33.7 MHz RFQ

Design Parameters

The RFQ is designed for an input dc beam of 1.38 keV/u, *q/A*=1/ 16, and resonant frequency of 33.7 MHz. The intervane voltage has been chosen to be 45.9 kV, which is about 1.12 times the Kilpatric limit for cw operation. With the interelectrode potential of 45.9 kV the calculated output energy comes out to be 29.06 keV/u for a vane length of 1.552 m. The radial matching section consists of 6 rf cells, and a total of 119 cells are needed to reach the energy. The synchronous phase in the acceleration section is chosen to be −30°. The calculated transmission efficiency is 95.8% for a beam current of 1 mA. The optimized physical parameters are shown in Fig.1. Energy width of the beam at the exit of RFQ is ± 0.67 keV/u.

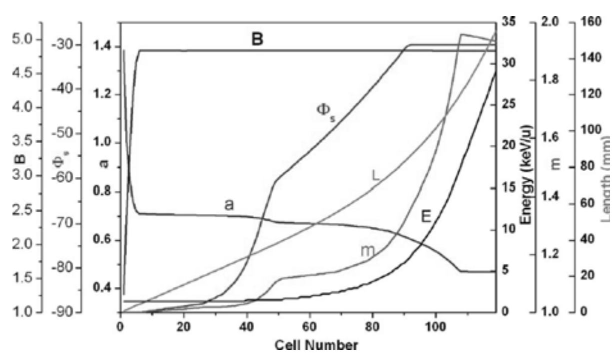

Figure 1: Optimised physical parameters variation along length of 33.7 MHz RFQ.

RF Analysis

MAFIA estimates resonant frequency, *Q*, and *Rp* values for the structure with unmodulated electrodes of the same characteristic radius to be 35 MHz, 9830, and 174 kΩ respectively. The measured resonating frequency is 33.7 MHz. The Q value measured using pick ups under 99% power reflection method is 5200.The tuning range of the tuner has been measured to be 100 KHz.

Beam Energy Measurement

Low energy beam transport line from ECRIS to RFQ consists of einzel lens,90^odipole for q/A selection and solenoid as matching element. The separation stage is designed for a dispersion of 1.84 cm. The ions are extracted from ECRIS at 1.38 keV/u. In the downstream of RFQ a QQD configuration has been installed for energy measurement. The quadrupole and dipole magnet strengths are calculated using TRANSPORT for RFQ beam energy of 29.06 keV/u, as theoretically predicted by PARMTEQ. The 5.4 m long beamline is designed for dispersion of 1.9 cm. The magnetic strengths of the quadrupoles and the dipole magnet are tuned so as to achieve maximum beam current on the Faraday cup (with electron suppression) placed upstream of the dipole after the RFQ. The beam tests have been carried out using oxygen ($^{16}O^{2+}$, $^{16}O^{3+}$, $^{16}O^{4+}$), nitrogen ($^{14}N^{3+}$, $^{14}N^{4+}$), and argon ($^{40}Ar^{4+}$).Typical transmission efficiency for most of the beams is 85% & 80% respectively for un analyzed and analyzed beam[5]. A plot of beam current measured on Faraday cup before RFQ as a function of vane voltage measured pickup voltage, proportional to vane voltage is shown in Fig.2.The transmission falls drastically when the vane voltage is reduced to a value lower than roughly 86.6% of the voltage corresponding to maximum transmission, as expected for the chosen synchronous phase of −30°.

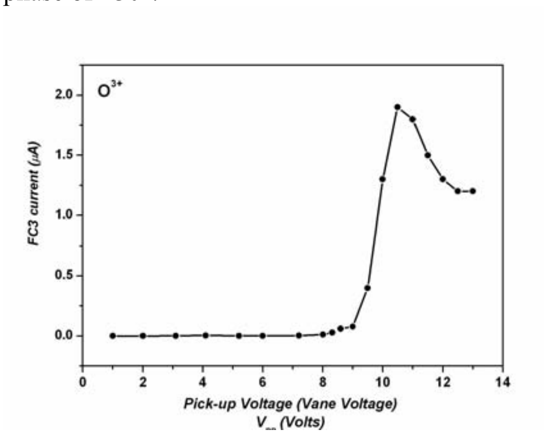

Figure 2: Variation of beam current with vane voltage for $^{16}O^{3+}$ beam.

37.8 MHz RFQ

Design Parameters

The RFQ has been designed for DC beams with input energy of 1.7 keV/u. The vane voltage of 53.7 kV accelerates the beam to energy of 98 keV/u over a length of 3.12m. This voltage is around 1.12 times of Killpatric Voltage of 47.65 kV. RFQ consists of 6 radial matching sections (RMS) and in all 147 cells. The potential formulation in the RMS is similar to that proposed by Yamada [6], where the focusing strength (B) obeys a sinusoidal variation over the length of RMS. The calculated efficiency for 1mA beam comes out to be ~96% The variation of the optimized physical parameters along the length of RFQ is shown in Fig 3.The minimum aperture radius is 4.1mm while the maximum modulation parameter is 1.388. Energy width of the output beam through the RFQ is around ± 0.3% of the final energy. Output beam distribution as calculated by PARMTEQ, both in longitudinal & transverse phase space is shown in Fig 4.

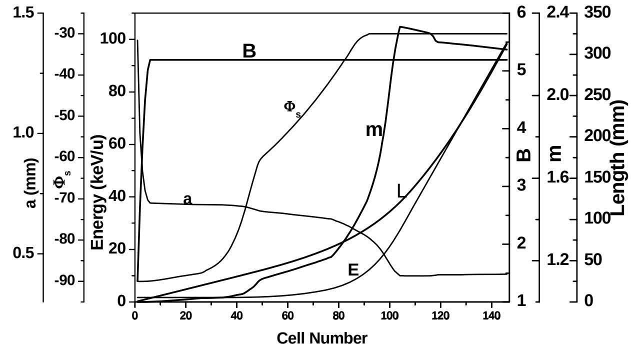

Figure 3: Variation of optimised physical parameters along the length of RFQ.

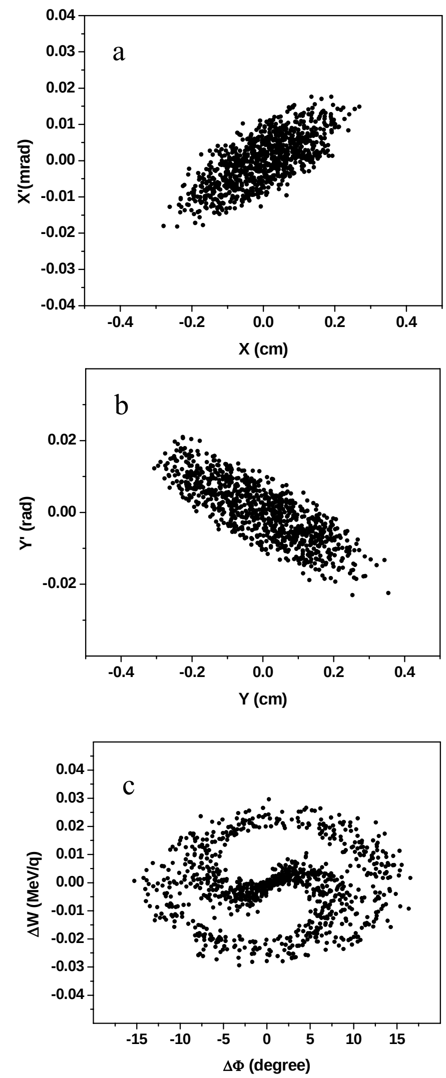

Figure 4: Longitudinal and transverse beam distribution at the exit of RFQ.

RF Analysis

The RF structure design was done using the code ANSYS. The resonant frequency, Q and R_p value simulated with unmodulated vanes having same characteristic radius are 37 MHz, 9763 and 78 kΩ respectively. Estimated power loss for 53.7 kV is around 18 kW. The resonance frequency is measured to be 37.8 MHz which is about 2% higher than simulated from ANSYS. The Q-value (Unloaded) measured using two pick-up loops under more than 98% reflection of power (-56 dB) is about 3705 (fig 5). The shunt impedance Rp was measured using both capacitance variation method (fig 6) and input admittance variance method. From both the methods Rp value comes out to be 53.65 KΩ and 53.9 KΩ which are about 68% of the calculated value.

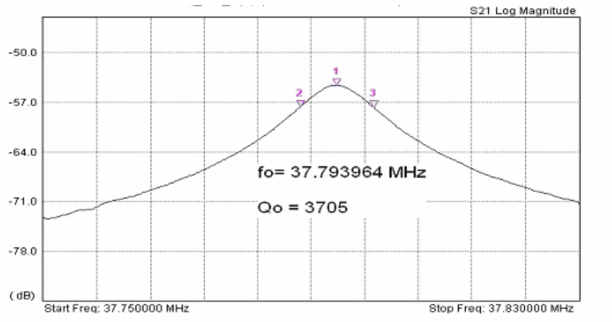

Figure 5: Unloaded Q value measurement using pick-up probes.

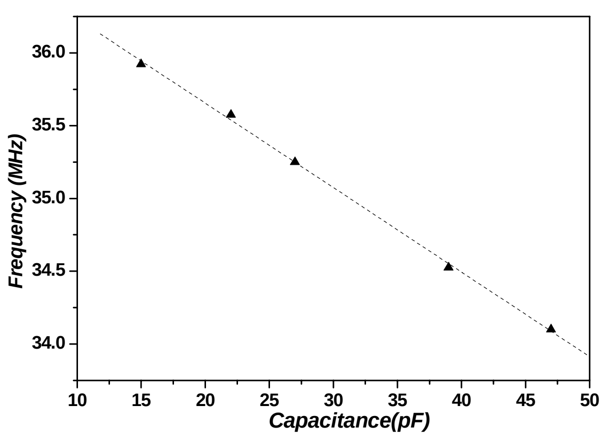

Figure 6: Rp/Q value measurement using capacitance variation method.

Beam Transmission Efficiency

The acceleration performance of RFQ has been measured with O(5+) beam extracted from ECRIS at 1.7 keV/u. After selection through 90 degree dipole magnet the solenoid is tuned in order to match the beam with RFQ. The ion optics has been calculated using TRANSPORT code. The strength of both the Dipole magnet and solenoid has been tuned accordingly. The transmission efficiency has been measured by taking the ratio of currents for faraday cups placed upstream and downstream of RFQ. Unanalysed efficiency is close to 90% for $O^{(5+)}$ beam.

Discussion

33.7 MHz RFQ have been successfully built and we are able to accelerate beam to 29keV/u with high enough efficiency through it. We have also succeeded in accelerating heavy ions such as Fe^{5+} through the RFQ for material science experiments. 3.4 m long RFQ have already been installed in the beam-line for accelerating heavy ion RI beams to 98 keV/u.Beam line after RFQ is in process of installation. A QQD configuration will be installed to assess the analysed beam transmission efficiency, in due course of time.

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