RF TESTING OF 75 MHZ PROTOTYPE HEAVY ION RFQ

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Abstract

The Heavy Ion RFQ at Pelletron Accelerator Facility (PAF), Mumbai is designed (75 MHz) to accelerate ions with q/m of 1/7 from 10 keV/u to 575 keV /u over a vane length of 4.62 m. A prototype heavy ion RFQ, 1.42 m long with 1.34 m of modulated vanes is designed and fabricated to study the RF properties. Measurement of resonant frequency (f_0), Quality factor (Q_0), and shunt impedance R_{sh} was carried out using Vector Network Analyzer is reported. The vane is fabricated without any joint, significant effort was put in measuring the longitudinal and transverse field profile along the RFQ which will be discussed. The outcome of experimental measurements and simulation is compared.

INTRODUCTION

A heavy ion RFQ (75 MHz) is being developed at PAF, BARC-TIFR. The beam dynamics design of this RFQ was reported earlier [1] which was carried out using LIDOS [2] software. It is designed to accelerate beam from 10 keV/u to 575 keV/u over a vane length of 4.62 m. An external buncher [3] was incorporated to reduce length & power consumption of RFQ which resulted in better longitudinal emittance at RFQ exit. A single gap third harmonic buncher with 75 MHz as fundamental frequency located 0.40 m upstream RFQ will be used to get bunched beam at RFQ entrance. A 1.42 m prototype RFQ with 1.34 m of modulated vanes (see fig. 1) is fabricated to study the mechanical fabrication aspects, RF properties & power coupling methods.

Figure 1: Fabricated Model of prototype RFQ.

The resonant structure of the RFQ consists of four electrodes called vanes, assembled in quadrupolar symmetry on support posts called stems arranged on a base plate. The resonant structure consisting of vanes, stems and base plate is enclosed in a vacuum chamber made of stainless steel. The electromagnetic design [4] of this RFQ was simulated using SOPRANO module of OPERA-3D software [5].

RF MEASUREMENTS

Frequency (f_0) & Quality Factor (Q_0)

The frequency (f_0) and Quality Factor (Q_0) of the RFQ was measured using Agilent E5071C Vector Network Analyzer (VNA). The measured frequency was 76.4 MHz (see fig. 2) using transmission method (S_{21}). No other mode exits within ± 20 MHz of resonant frequency, the closest one at 123 MHz. An inductive loop was used to feed power to RFQ at one end and pick up loop was used at diagonally opposite end. Using 3dB method, the unloaded Quality Factor (Q_0) measured was 2300.

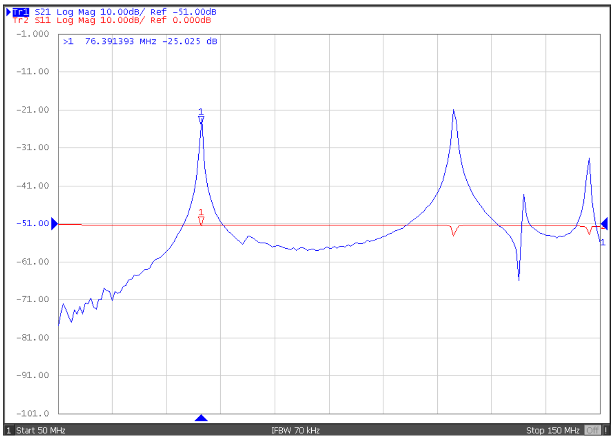

Figure 2: Frequency Spectrum of Prototype RFQ.

Shunt Impedance (R_{sh}) Measurement

Capacitance variation method was used to measure the shunt impedance. The inter-electrode capacitance in each quadrant was varied from 0 to 30 pF and change in resonant frequency was recorded. The average slope of dω/dc (see fig. 3) is used to calculate R_{sh} using the relation:

$$R_{sh}/Q_0 = -2/\omega_0^2 \,(d\omega/dc)$$
$$= -1/\pi f_0^2 \,(df/dc)$$

The measured Shunt Impedance is in the range of 30 -60 KΩ.

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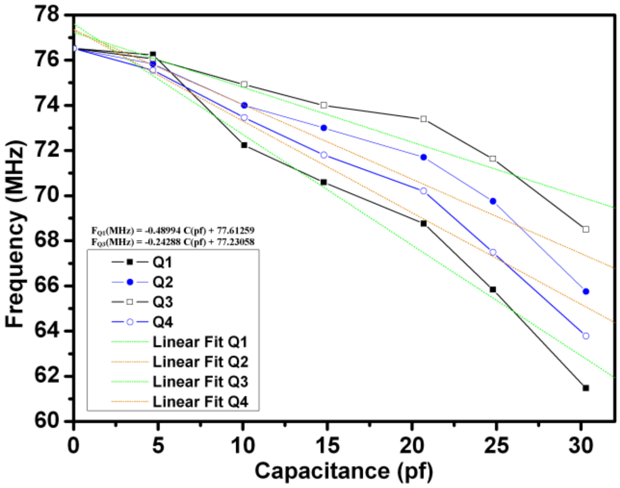

Figure 3: Variation of Frequency with Capacitance in four quadrants of RFQ.

E-Field Measurement

The measurement of longitudinal electric field is the single most important parameter which governs RFQ performance. Bead pull technique is used to measure the electric field profile along the z-axis. Initially Teflon bead of 3 mm diameter was used but it gave poor signal to noise ratio. Then TiO_2 cylindrical bead (3 mm diameter, 6 mm length) was used to improve the signal to noise ratio. Dielectric constant of TiO_2 is 100 compared to 2 for Teflon. The longitudinal field profile (see fig.4) along the RFQ (from higher modulation side to lower modulation side) indicates that alignment and machining of truncated vanes requires improvement. The number of accelerating cells (see Fig. 5) matches with the design values.

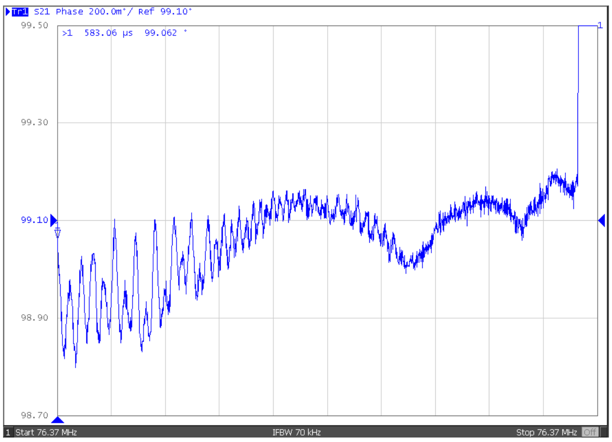

Figure 4: E-field along 1.34m vane length.

VACUUM TESTING

The achieved vacuum in the stainless steel chamber fabricated for prototype RFQ was 2 x 10^{-7} torr. With the RFQ structure installed in the chamber, 5 x 10^{-6} torr was achieved after 20 hours of continuous pumping with a 80 Litres capacity Turbo Molecular Pump. A 100 watt RF amplifier was available for initial conditioning of RFQ. The forward and reflected power measurements were done at different power levels. Reflected power of less than 1% was obtained in the best coupler position when tests were conducted in air. When power was fed to prototype RFQ in vacuum, an increase in the reflected power was observed. The best figure achieved so far is 20-30%. However this has to be verified in terms of the stability and repeatability. This variation of reflected power with vacuum needs proper investigation to understand the RF to vacuum coupling.

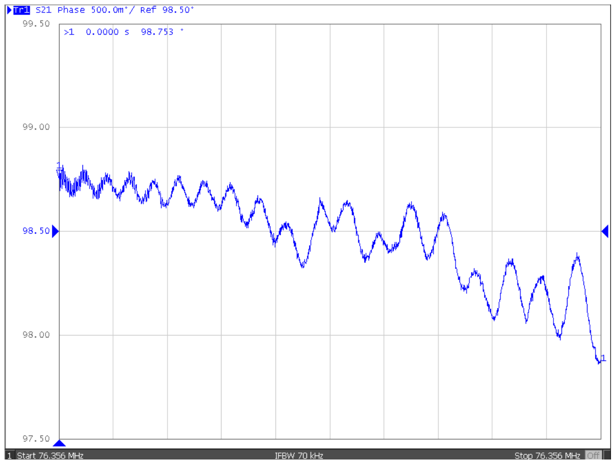

Figure 5: E-field along high modulation 44cm length.

CONCLUSION

This prototype RFQ will serve as a model to characterize all aspects of RFQ fabrication, assembly, vacuum tests, power feeding and coupling with RF power up to 1KW. The RF properties measured give an estimate of RF power requirement. The table below summarizes the simulated and measured RF parameters for this RFQ:

Table 1: RF Parameters

RF Parameters	Simulated	Measured
f_0, MHz	75	76.4
Q_0	6500	2300
R_{sh}, KΩ	140	30.46-61.4
P, kW	45	102-206

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[3] N. Mehrotra et al., Beam Dynamics of the heavy ion RFQ with prebuncher for the alternate injector at PAF, InPAC-2006, November 1-4, 2006, BARC/TIFR, Mumbai, pp. 215-216.

[4] N. Mehrotra et al., Electromagnetic Design Study of RFQ, InPAC-2009, February 10-13, RRCAT, Indore.

[5] OPERA-3D/SOPRANO v11.0 ©Vector Fields Limited, Oxford OX51JE, U.K. http://www.vectorfields.com/