COMMISSIONING EXPERIENCE OF THE LPRFQ ACCELERATOR

R.C.Sethi, V.T.Nimje, K.P.Dixit, M.Sengupta, A.J.Dabeer, R.S.Sardesai and K.L.Gupta
Accelerator & Pulse Power Division, BARC, Mumbai 400 085, India

Abstract

A Low Power RFQ (LPRFQ) accelerator, capable of delivering 125 keV/250 keV, proton/deuteron beam respectively, has been designed, developed and commissioned with a proton beam at BARC. The RFQ uses a four rod trapezoidal configuration for the electrodes and is operated at an RF frequency of 56 MHz, with a duty cycle of ~ 2%. A proton beam from the duoplasmatron ion source, injected at an energy of 4.7 keV is accelerated to 110 keV, with an effective transmission of 50%. The results are optimum at an RF power level of 4 kW. Further work on beam matching, diagnostics and analysis is in progress.

1 INTRODUCTION

Radio Frequency Quadrupole (RFQ) accelerators are the modern tools which deliver highly intense beams to the tune of 100 mA or more. This is the main reason that they are being employed as injectors to high energy machines, used for basic sciences, spallation neutron sources, fusion devices and accelerator breeders. In order to have a proper understanding of the various issues involved in designing, developing and commissioning the RFQ, a prototype Low Power RFQ (LPRFQ) was conceived and developed at BARC[1].

An isometric view of the LPRFQ is shown in Fig.1. The electrodes are in the form of 4 rod structure having trapezoidal configuration in the longitudinal planes and circularin the transverse plane. The length of the electrodes is 0.905 metres, including a radial matcher length of 2 $\beta\lambda$. It is designed for a maximum modulation factor of 2, leading to a maximum electrode diameter as 22 mm with a minimum bore of 5 mm for beam acceleration. The beam behaviour in the LPRFQ was studied using computer codes like RFQTRAP[2] and RVBEAM[3]. The stabilities in both the planes limited the proton beam current to ~ 3 mA at an interelectrode voltage of 15 kV. The same geometry can give a deuteron beam of 250 keV at an interelectrode potential of 30 kV. The RF structure is of zero mode – $\lambda/2$ type. The voltage on the electrodes is built with the help of 5 stems, each separated by a unit RF cell[4] of 200 mm. The tuning plates are stationed at the base of 300 mm high stems. The whole assembly can slide into the RF tank which is copper-electroplated from inside. The RF contacts between the RFQ assembly and the tank are established with the help of Be - Cu strips, evenly distributed along the length of the accelerator. The tank is equipped with various ports where the input loop and capacitive pick-up probes are installed. The input loop is movable and its positions can be adjusted to achieve proper impedance matching between the RFQ system and the RF power source. Further, a matching network employed in series minimises the reflections and transfers maximum power to the RFQ. The system is evacuated to ~ 10^{-6} with the help of turbomolecular pump. On the basis of the theoretical design, an unmodulated structure, having the equivalent LC, was built for measuring and optimising various RF parameters. The model studies for evaluating the frequency shift were carried out on the RF stem structure by moving the tuning plates towards and away from the electrodes. About 0.8 MHz change could be

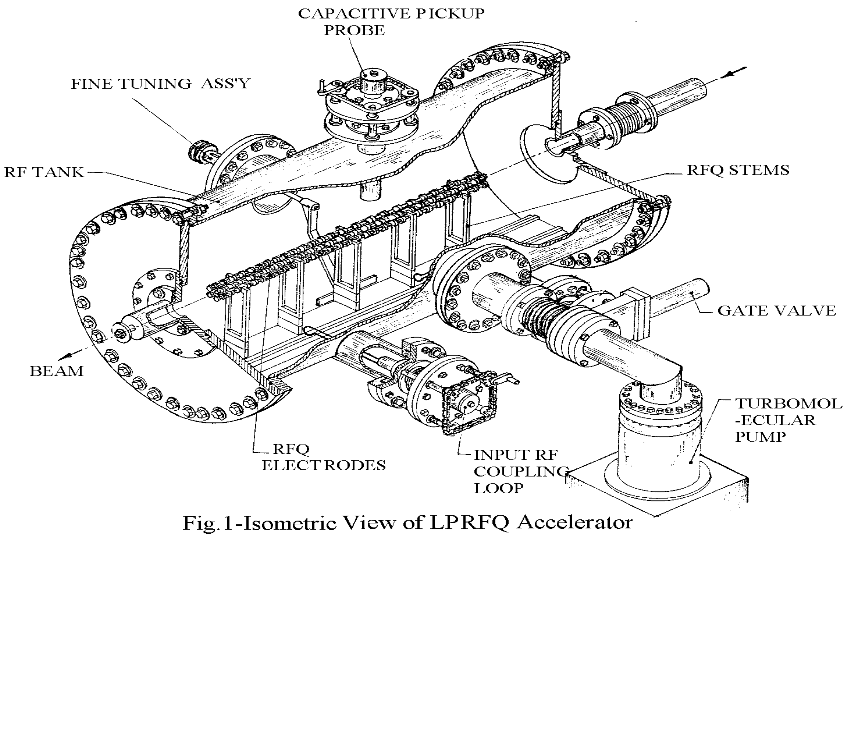

Fig.1-Isometric View of LPRFQ Accelerator

achieved by a movement of 1cm. The electrodes were fabricated on CNC machines and the stems on jig boring machines. The necessary corrections were carried out in the actual modulated structure. It was possible to achieve a final tolerance of ± 150 microns in the entire RFQ

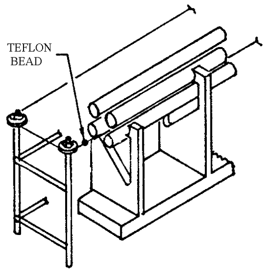

Fig.2-Bead Perturbation Assembly

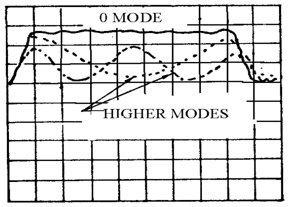

Fig.3- Electric Field Distribution of various modes

assembly after hydrogen furnace brazing. The results of the RF measurements and beam commissioning are given in the following sections.

2 RF TESTS

For the determination of the parameters such as resonant frequency, modes of the cavity, Q-value, shunt impedance and electric field distribution, RF tests[5] were conducted with the network analyser, at 5 mW RF power. The entire spectrum between 1 MHz and 1 GHz was scanned and peaks at various frequencies were observed. In order to identify the required zero mode and the higher harmonic modes of the LPRFQ, the electric field distribution was studied at the various peaks, using the bead perturbation technique. In this method, a cylindrical teflon bead (5.1 mm long, 3.7 mm dia.) was introduced in the electrode gaps, as shown in Fig. 2 and the resulting phase shift was studied. Fig.3 shows the electric field distribution of the zero mode and other higher harmonic modes. The zero mode resonant frequency was identified at 55.166 MHz.

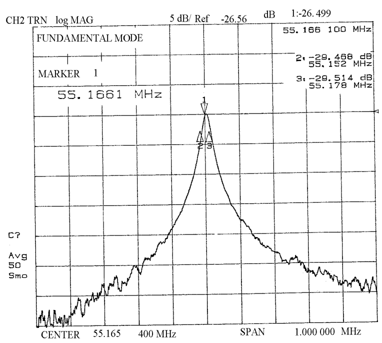

Fig.4 - Q - value Measurement

Unloaded Q of ~ 2200 was measured, as shown in Fig.4. The loading effect of the input loop was studied at an RF power of 30 watts, by moving it towards and away from the stem.

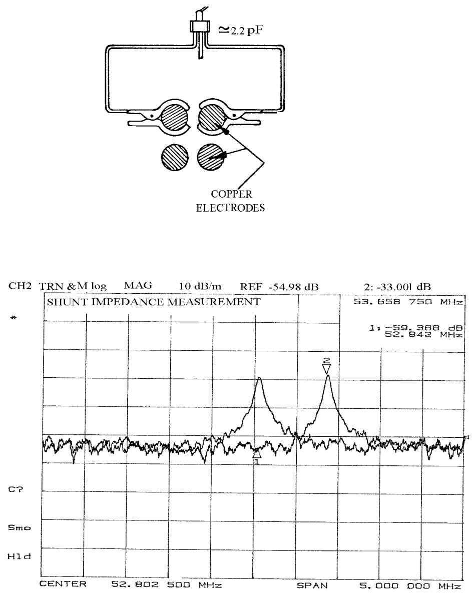

Fig.5- Setup and Results of Frequency Shift Method for the Measurement of Shunt Impedance MHz.

A distance of 9 mm of the input loop from the stem was found to be the optimum position for maximum voltage buildup and matching. Loaded Q, at this position, was found to be ~1500.

The shunt impedance was measured by the perturbation method[6]. A known capacitance of 2.2 pF was introduced into the system having a total capacitance of ~ 100 pF and the resulting frequency shift was observed as shown in Fig.5. The unloaded shunt impedance worked out to be ~40 kΩ while the loaded shunt impedance is found to be ~30 kΩ. Alternatively, the phase shift method[6] was employed to verify the results obtained with the frequency shift method. In this case, the

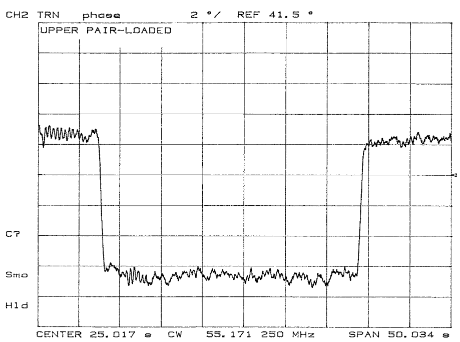

Fig.6- Results of the Phase Shift Method

field distribution of zero mode, as shown in Fig.6, gives a phase shift of 12° in the presence of the teflon bead, as the perturbing object. From this, unloaded shunt impedance works out to be ~ 35 kΩ, whereas the 8° phase shift in the loaded case gives a value of ~ 32 kΩ. The asymmetry in electric field distribution in the four gaps, in the longitudinal and azimuthal directions was measured to be within ± 5%. To ensure stable field conditions, under high RF power, baking of the system was carried out at a pressure of 5 x 10^{-6} torr. In the continuous mode, a maximum of 700 watts of RF power was fed into the system, while in the pulsed mode, 5 kW was the maximum power level. The x-ray end-point energy method[7] was employed to determine the voltage difference between the electrodes at an RF power level of ~ 5 kW. X-rays emitted by field emission were passed through an Al window (70µ thick) and detected with the help of Si(Li) detector. The spectrum shown in Fig.7, indicates an end-point energy of ~19 keV, which corresponds to an interelectrode voltage of ~19 kV.

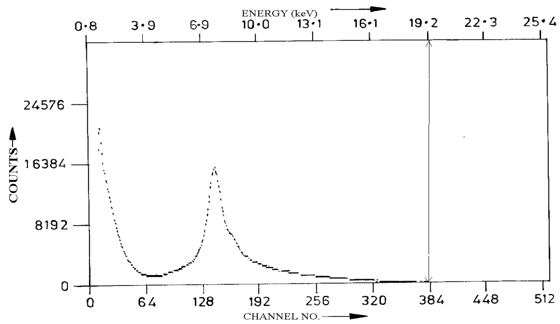

Fig.7- X-Ray Spectrum for Voltage Measurement

3 BEAM MEASUREMENTS & ANALYSIS

Based on the above experiments, the necessary changes were incorporated in the modulated LPRFQ structure. The unloaded Q of ~ 2500 was measured at the resonant frequency of 55.5 MHz. A proton beam of ~ 100 µA from a duoplasmatron ion source[8], at an energy of 4.7 keV, was injected into the LPRFQ and the emergent beam was characterized for its current and energy, by the following methods.

The presence of beam was detected on a ZnS screen mounted at a distance of 1 m from the output end of the LPRFQ tank. The beam behaviour was observed with the variation of injection energy, RF power level and frequency. At a frequency of 55.438 MHz and RF power of 4 kW, an intense glow was observed. The beam current at the end of the RFQ at this stage was measured to be ~ 10 µA. For the confirmation of the beam energy, a 90° double focussing magnetic analyser was installed in the beam line, along with steerer assembly. After optimising the magnetic field, the transmitted beam was measured at a field level of 2 kG, which corresponds to an energy of 110 keV protons. Successively by optimising the various parameters of the RFQ, a maximum beam current of 60 µA has been achieved at the output end of RFQ. It has also been confirmed that below RF power level of ~ 2.5 kW no beam could be observed. The variation in the injection voltage, einzel lens voltage and the RF frequency had to be kept within 0.94 kV, 1.3 kV and 18 kHz respectively. Beyond these limits the beam vanished completely.

4 CONCLUSION

The LPRFQ accelerator has now been adopted as an R&D tool to carry out further RFQ accelerator development. So far, a beam transmission of ~ 50 % has been obtained, without the use of beam matching devices. Such devices will be incorporated at the injection side of the RFQ. Serious efforts are being made to measure the emittance of the beam. Suppression of the RF pickup on various measurement devices has also been undertaken. Other beam diagnostic devices are being added on the injection side in order to obtain more information about the beam properties. These measures will ensure better beam quality with improved transmission.

5 ACKNOWLEDGEMENTS

The authors would like to extend their gratitude to Dr.S.S.Kapoor and Dr.P.H.Ron for their keen interest, constant support, and encouragement.

6 REFERENCES

[1] R.C.Sethi, “RFQ Accelerator Development”, Indian Journal of Pure & Applied Physics, vol.35 (1997) 156
[2] P. Junior et al., Lecture Notes in Physics (Springer Verlag, Berlin) 215(1984)206
[3] V.T.Nimje and R.C.Sethi, Private Communication
[4] A.Schempp, et.al., IEEE Tr.NS 30, No.4 (1983) 3536
[5] K.P.Dixit, " Design Studies, Modelling and Testing the RF characteristics of the RFQ Accelerator", M.Sc.(Engg) thesis, Indian Institute of Science, Bangalore, India, 1997
[6] P.Junior, "Comments on the Bead Perturbation Method", Frankfurt University, Internal Report 87-1, 1987
[7] J.Brutscher, et. al., “Measurements of the gap Voltage in RF cavities with a x-ray spectrometer”, GSI Report GSI-88-17, pp 34
[8] N.M.Thakur & R.C.Sethi, “Operational characteristics of the ion source for the RFQ”, Review of Scientific Instruments, vol 63, (1992), 2621