Frequency Tunable 4-rod RFQ

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Abstract

The frequency tunability of the 4-rod RFQ is investigated. The experimental results show that the resonant frequency can be varied almost twofold by moving the shorting electrodes between the posts, which support the 4-rod electrodes from the base. In that configuration the shunt impedance is found to be low at higher frequency region. An additional ON-OFF posts-shorting electrode above the electrodes can overcome this draw back. It raises the resonant frequency without lowering the shunt impedance too much and when used with the moving shorting-plates it expands practically available resonant frequency range. Because the ON-OFF shorting electrode requires no sliding rf contact, this device is simple and easy to fabricate. The effect of the proposed ON-OFF shorting electrode is studied by MAFIA.

Introduction

A 4-rod RFQ is suitable for a heavy ion accelerator because it operates in low resonant frequency in relatively small size [1-3]. To accelerate various ions of nuclear species, the inter-electrode voltage should be varied or, the resonant frequency should be changed because the charge to mass ratio of those ions cannot be held constant. For a distributed circuit resonator such as conventional 4-vane cavity RFQ, it is difficult to have a large resonant frequency range without suffering the flatness of its electric field distribution. On the other hand in the 4-rod RFQ structure, the balance of the field distributions remain relatively unchanged in a wide range of its operating frequency. This is due to the fact that it is determined mostly by the mechanical configuration of the RFQ structure.

We have measured the rf characteristics—the longitudinal field distribution and the Q-value—of an RFQ cold model, changing its resonant frequencies [4]. In addition MAFIA calculations have been performed to make computational predictions and comparisons with the results of the model studies. Two independent methods of changing the resonant frequency of the 4-rod RFQ structure are presented.

Frequency Change by Movable Posts-Shorting Plates (first method)

The resonant frequencies are varied by the position of the shorting plates which are movable between the vertical electrode-supporting plates—what we call posts. It reduces the effective heights of the posts, therefore it reduces their inductance as a result. Two pairs of the un-modulated electrode rods forms RFQ fields, each pair being held by three posts. There are six posts in total. The posts are equally spaced and fixed onto a flat base-plate. The whole RFQ electrode assembly can be moved out from the tank. The movable shorting plates are made of aluminum, 20 mm in thickness and have copper rf contacts. The positioning of the shorting plates—changing the effective height of the posts—are done accurately using a combination of various fixed-length spacers.

Measurements on the Cold Model

Measurements were performed on the cold model cavity which had been fabricated as a 1/3 scaled model of the 33 MHz 4-rod RFQ (See Photo. 1) [1]. The resonant frequency was 110.1 MHz when the shorting plates are placed on the base plate. In order to evaluate the shunt impedance, we measured the variations of the resonant frequency moving a cylindrical dielectric bead on the beam axis. The results are shown in fig. 1. The uniformity of the distributions become worse as the position of the shorting plates get close to the beam optics axes—as much as 15% bump of inter-electrode voltage was observed when the distance between the top of the plate and the beam optics axis was 30 mm. Because of the less stiffness of the posts, the inter-electrode distance was thought to be moved by the pressure of the rf contactor of the shorting plates. Considering the fact that the distances between the top of the plates and the electrode edge are only 10 mm, we think the field stability is good. The noise level became large as the resonant frequency was raised. This was due to small rf coupling.

Because the bead was moved on the axis, there was a possibility for the results being interfered with excitation modes other than quadrupole. Because the uniform

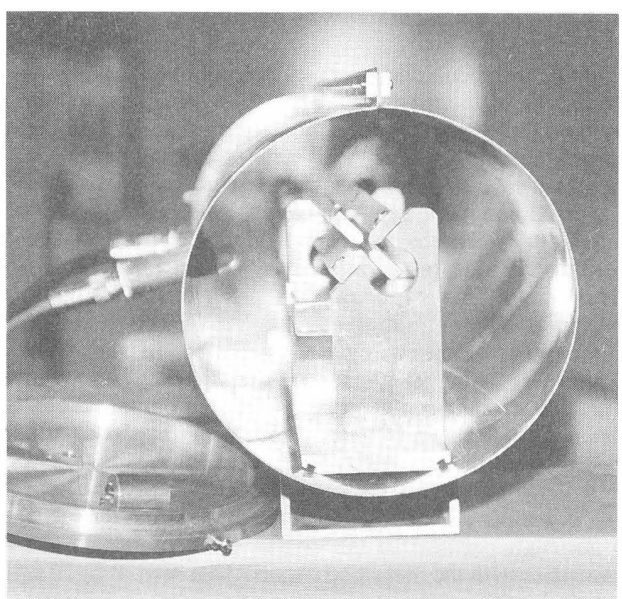

Photo. 1 1/3 scale 4-rod RFQ cold model

mixture of the dipole component along the axis is equivalent to the offset of the quadrupole center, it can be compensated by shifting the beam optical axes.

We are interested in the variation of the shunt impedance as a function of the frequency. The shunt impedance is defined by the square of the inter-electrode voltage V divided by the power loss P in the tank. Bead pull measurements give

$$\frac{\Delta f}{f} \propto \frac{V^2}{W}, \tag{1}$$

where W is the stored energy in the tank. Because of the on axis measurements of the bead, it is a relative value. The shunt impedance is expressed by

$$Z = \frac{V^2}{P}. \tag{2}$$

The Q value is defined by

$$Q = \omega \frac{W}{P}. \tag{3}$$

Then we get

$$\frac{Z}{Q} = \frac{V^2}{\omega W} \propto \frac{\Delta f}{f^2}. \tag{4}$$

The shunt impedance Z was obtained as

$$Z \propto \frac{\Delta f}{f^2} Q. \tag{5}$$

The measured resonant frequency and the shunt impedance are shown in fig. 2 as a function of the shorting plates position. The shunt impedance decreases as the resonant frequency goes up. The resonant frequency raises to 1.8 times of the original value. In this model, the operating mode which is a fundamental mode has the lowest frequency and the next mode has about double of that frequency. The second mode is pushed up slightly as the shorting plates go up. This mode is the second quadrupole in which current nodes exist at the middle of the rod electrodes. Because no current flows on the posts, it is independent of the posts structure. The frequency range of the fundamental mode with this scheme is limited by this.

Calculations by MAFIA

MAFIA calculations were carried out to compare with the results of the model studies [5]. Figure 3 shows the typical mesh used for the calculations. Because of the limited computing time and mesh size, the generated meshes were not exactly the same geometry as the cold model. Although the vane tip was approximated by square corners in this mesh, it can simulate the electro-magnetic field distribution in the real cavity except for near axis distribution. This is because the mesh geometry can give the good approximation of the real inter-electrode capacity. Because we were interested in the field distribution along the beam axis and the Q-value, the coarse mesh was good enough to fulfill our purposes. Fig. 4 shows the resonant frequency and shunt impedance as a function of the shorting plate position. This shunt impedance represents the calculated value of the shunt impedance per cavity. Although the precision of the value is not high because of the coarse mesh, it is in good agreement with the measured results. Also seen in fig. 4 is that the position dependence on the frequency is larger at the higher frequency or closer position to the axis.

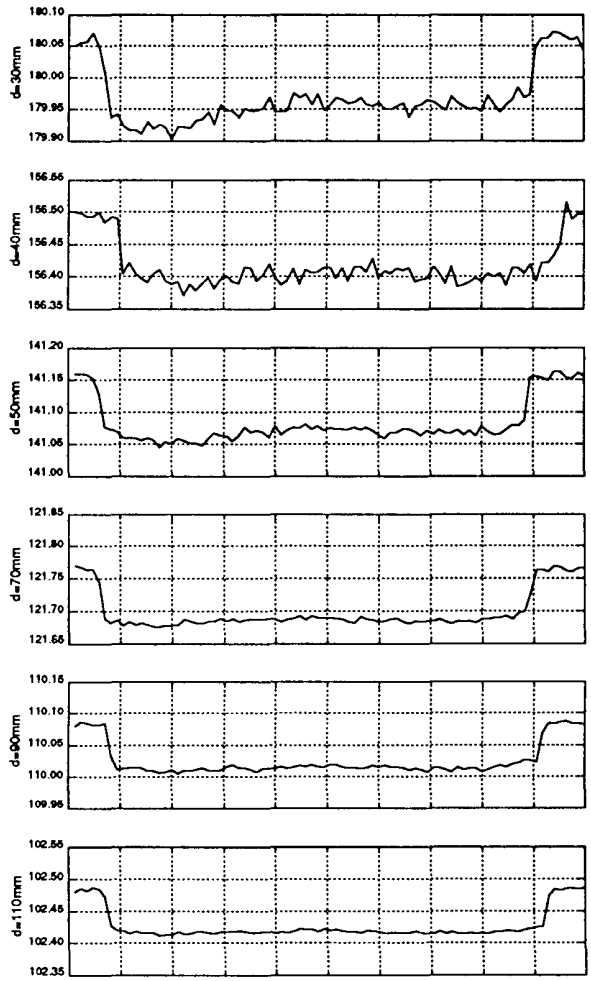

Fig.1 Bead-pull results of the 1/3 cold model at 6 different shorting plate positions; d corresponds to the distance between the beam axis and the shorting plate. The numbers in the ordinates are the resonant frequencies in MHz.

Frequency Change by Posts-Shorting Bar over The RFQ Electrodes (second method)

Using the movable posts-shorting plate, the frequency could be changed about 1.8 times. More accelerating field is required in RFQ when the resonant frequency is high. Because the value of the shunt impedance decreases at the higher frequencies, the power requirement becomes large. In order to reduce the power requirement and expand the frequency range, an additional posts-shorting electrode was proposed. The extra posts-shorting bar is installed over the posts, and is able to short the posts at their top surfaces. Because it is an ON-OFF device, the structure is simple and easy to fabricate. The effect of this device was evaluated by MAFIA calculations considering only one section between the adjacent posts. The situation is depicted in fig. 5. The posts are modified so that it has an additional top half arm to obtain larger contact surface. This configuration also has an effect in reducing the field asymmetry on the beam axis. Fig. 6 shows the calculated resonant frequency and the shunt impedance as a function of the distances between the movable posts-shorting

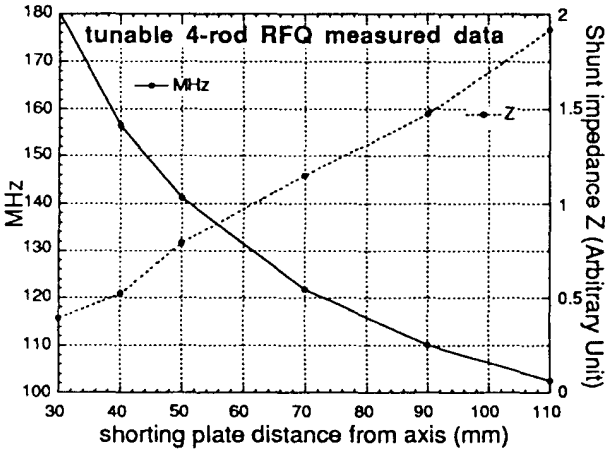

Fig. 2 Resonant frequency as a function of the shorting plate distance from the beam axis. The shunt impedance is also shown.

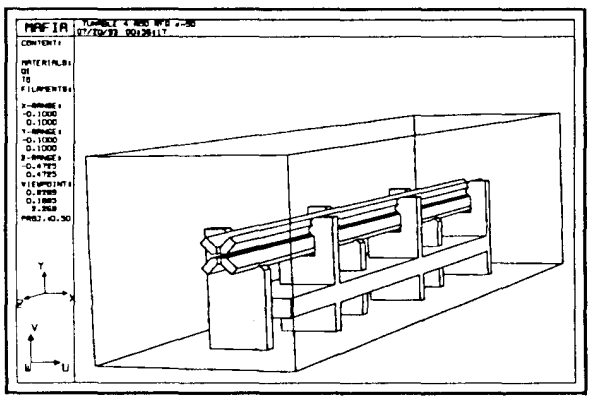

Fig. 3 Generated mesh used in MAFIA calculation.

electrodes and the beam axes for the both positions of the ON-OFF posts-shorting bar. The variable resonant frequency range was expanded by this device. Fig. 7 shows the shunt impedance as a function of the resonant frequency for the both positions of the ON-OFF posts-shorting bar. At higher resonant frequency, higher shunt impedance is available using the ON-OFF posts-shorting bar.

References

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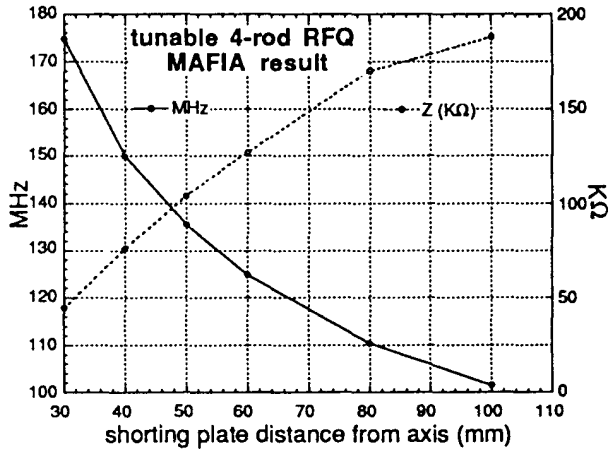

Fig. 4 The results of MAFIA calculations.

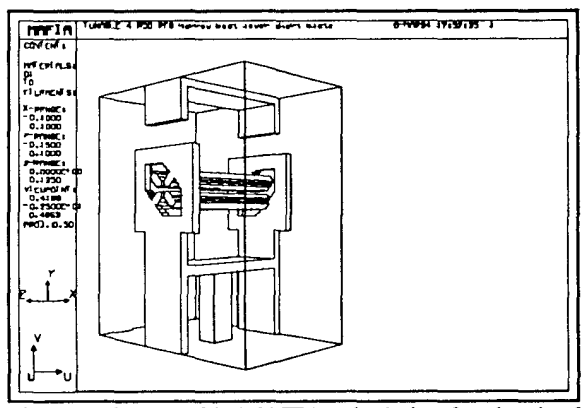

Fig.5 Mesh used in MAFIA calculation for shorting bar.

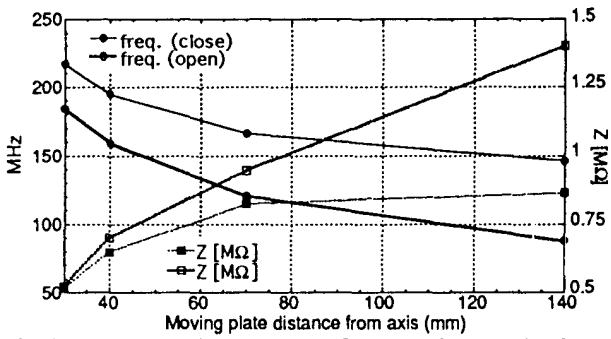

Fig.6 A Plot of resonant frequencies and shunt impedance as a function of the positions of the movable shorting plates for both positions of the ON-OFF posts-shorting bar.

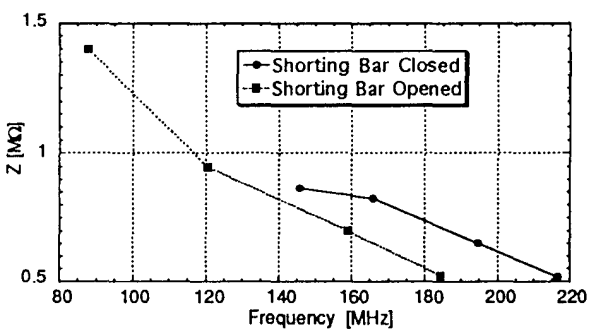

Fig.7 A plot of shunt impedance as a function of resonant frequency. Using a ON-OFF bar is advantageous.