RF-DESIGN OF A 325 MHz 4-ROD RFQ*

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Abstract

Usually 4-ROD Radio Frequency Quadrupoles (RFQ) are built for frequencies up to 216 MHz. For higher frequencies 4-VANE structures are more common. The advantages of 4-Rod structures, the greater flexibility for tuning and being more comfortable for maintenance, are motivating the development of a 4-Rod RFQ for higher frequencies than 216 MHz. In particular a 325 MHz RFQ with an output energy of 3 MeV is needed for the proton linac for the FAIR project of GSI. This paper reports about the design studies and the latest developments of this RFQ.

INTRODUCTION

At present the highest 4-Rod RFQ frequency is 216 MHz for higher frequencies 4-VANE RFQs are usually used. By enhancing the frequency the geometric size of the structure becomes smaller. This effect causes some challenges on building a 4-Rod RFQ for higher frequencies for example the dipole field that disturbs the quadrupole field of the electrodes (see proceeding [1]).
Up to now design studies and simulations have shown that it is possible to eliminate the dipole field overlaying the quadrupole field. The next step is to fit the new findings to 325 MHz and the present state of the RFQ design. Therefore further simulations have been done on the field geometry and the influences of parameter changes on the resonator values.

SIMULATIONS

Simulations have been done using CST Microwave Studio® on a short RFQ structure of only 6 stems to reduce solver time. An 4-Rod RFQ can be described as a chain of $\lambda/4$ resonators that are operated in π-0-mode. Due to this the physical behavior does not change with different stem numbers except the small influence of the electrode overlap causing some more capacitance.

Present RFQ Design

The research on reducing the dipole field has been done on a very basic RFQ simulation model. This simulation model and the present design differ mainly in the stem thickness and the connection from the stems to the electrodes. Due to the sensitive behavior regarding parametric changes additional simulations on the aperture and electrode tip radius and some readjustment of the dipole have been executed. Figure 1 shows the former and the present simulation model.

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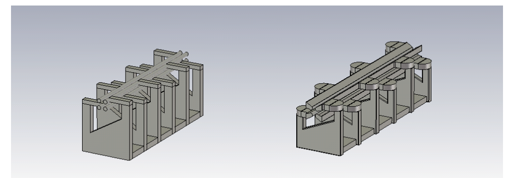

Figure 1: Former an present simulation model.

One difference between the former and present model are the different clamp shapes. They connect the stems with the electrodes. In the past they have just been trapezoidal. Now they are semi circle shaped and allow a more precise adjustment of the electrodes but have a greater capacitance. This lowers the frequency of the RFQ. The optimization of the shape for the 325 MHz structure is still in progress.
The electrodes of the present model consisting of a rectangular back and a circle shaped electrode tip and advance the geometry of the quadrupole field, allowing more flexibility in choosing the aperture and the electrode tip radius. Furthermore this shape is better for alignment as well and provides a better mechanical stability.
The stems are thicker in the present model and have rounded edges. This shape is matching the magnetic field surrounding the stems. Due to these improvements the ideal cutting of the stem respectively the stem shape has to be found again for elimination of the perturbing dipole field.

Parameter Variations

To find the right parameter settings for the present RF structure that eliminates the dipole field research had to be done on single parameter changes to understand their influence more accurate. The several parameter changes that had been analyzed are illustrated in figure 2.

Besides the stem cutting simulations on the aperture, the clamp height, the width of the stem arms, the stem width and the stem distance have been executed to study their influence on the frequency, the field geometry and the dipole field.

Variation of the Stem Cutting A deeper stem cutting provides more space for the magnetic field surrounding the stem arm. This causes more charge transportation to the lower electrodes to adjust the dipole field. For further details see proceeding [1].
Simulations on the new model of the stem cutting have led to a reduction from 35% to 18% but not to a compensation of the dipole field. This was a first rough approximation without an adjustment of the aperture and electrode tip

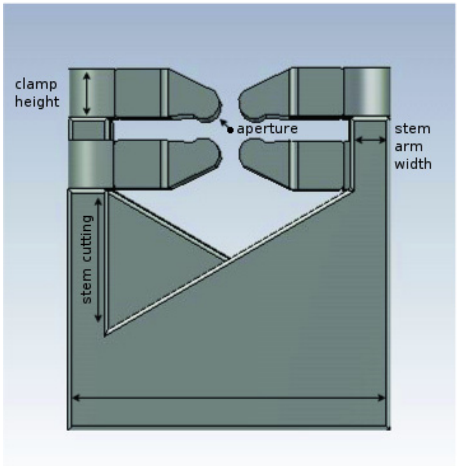

Figure 2: Parameter variations of the stem shape.

radius. But nevertheless this made further variations of different parameters necessary.

Variation of Aperture The change of the aperture mainly changes capacitance. The resonance frequency is given by the Thomson formula

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{1}$$

so the change of the aperture has a strong influence on the resonance frequency and the dipole field.
The research on different apertures has shown that the frequency increases and the dipole decreases with larger apertures. A minimal dipole could be found by a ratio of the electrode tip radius to the aperture ($^{Er}/_{A}$) of 0.5 whereas usually a ratio of 0.8 is used. This makes the RFQ better comparable to other RFQs, so the following simulations have been executed with the 0.8 ratio. For the simulations a mean aperture was used because due the beam dynamics calculation the aperture is changing along the structure.

Variation of the Clamp Height Variations of the clamp height of the electrodes have shown a dropping of the frequency and of the dipole field with increasing clamp heights. In addition with the stem cutting this led to a dipole field of only 9% but a lower frequency than desired. The variation of the clamp height and the clamp thickness is shown in picture 2. The bigger clamps are causing more capacitance. Due to the fact that the dipole component is weaker at lower frequencies the dipole has to drop as well. Thick clamp heights can pull parts of the electric field between the upper an lower clamps causing losses. So one has to regard this changes carefully.

Variation of the Width of Stem Arms This simulations have shown a slight lowering of the frequency as well as the dipole field with decreasing width of the stem arms. So this parameter change was disregarded for the first time but was kept in mind.

Variation of the Stem Width The stem width was varied between 70 mm and 120 mm. The enhancement of the stem width led to a slight dropping of the resonance frequency and a reduction to a complete compensation of the dipole field.

Variation of the Stem Distance The stem distance mainly changes the frequency, so it can be used to adjust the frequency in simulations after all parameter settings are done. Besides this simulations have shown, that the stem distance has an influence on the dipole field as well. The stem distance was changed from 35 mm to 75 mm with a frequency deviation between 395 MHz and 225 MHz. The dipole field could be minimized to 4%.

Figure 3: Stem width and stem distance of the RFQ structure.

With regard to the construction and tuning of a RFQ a greater stem distance would be desirable. The simulations have shown that a stem distance of about 50 mm lead to the best results concerning the RF design of the structure.

Field Geometry

By changing parameters one has to regard the total field geometry as well. For example if the clamp height is too large it gets so close together that its capacity causes a field between the upper and lower clamps which brings inhomogeneity into the quadrupole field. It is possible to have no dipole field between the upper and lower electrodes but between the left and right ones. On figure 4 one can see that parts of the field can be distributed towards the stem arms. This fact is not necessarily causing problems with the quadrupole field but it can cause undesired losses. So the variation flexibility is limited in order to avoid such losses.

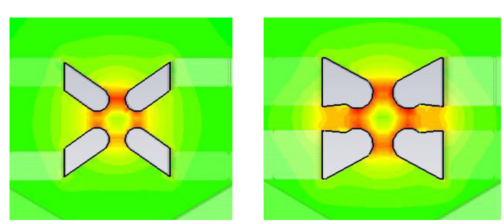

Figure 4: Field geometry of two different clamp heigths.

In addition the research on one parameter is often limited by another parameter setting or by parameters given in respect to the construction. For example a large aperture can be restricted by the size of the stem arms or as another example if the electrodes need to be water cooled it has to have a minimal size given by the water pipe.

Results

Through the simulation work on the different parameters and their influence on the whole RFQ, two structures meet the requirements to be build as a prototype. One of them has thicker stems and a higher beam line, the other one has a narrow stem width an a lower beam line. Type II has less aperture and electrode tip radius and a less steep stem cutting than type I. The basic differences of the structures are listed in tabular 1. The dipole is shown in line U/L. This is the ratio of the voltage distribution of the upper to the lower electrodes.

Table 1: 325 MHz Structure Types

Parameter	**Type I**	**Type II**
Beam Line Position [mm]	75	60
Stem Width [mm]	100	63
Stem Distance [mm]	50	50
Mean Aperture [mm]	5	2.67
Electrode Tip Radius [mm]	4	2.2
Clamp Height [mm]	12	8
Width of Stem Arm [mm]	10	10
Frequency [MHz]	307,5	307,1
U/L	1.05	1.00
Tuning Plate Shift [mm]	15	10
Frequency Shift [MHz]	24,4	26,9
Quality Factor	4100	3600
Shunt Impedance [kΩm]	47	35

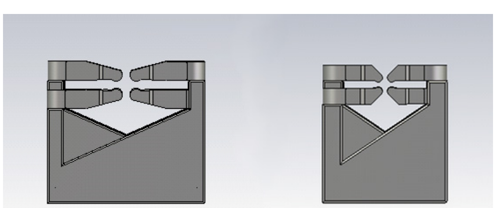

Figure 5: 325 MHz structure types. Type I (left) type II (right).

Both react quite sensitive on parameter changes, so it does on changing the height of the tuning plates for the frequency adjustment. This makes the tuning of a long structure with many RF cells challenging but possible. Moreover the research and knowledge about behavior of the structure on parameter changes makes it easier for tuning.

Type II has a frequency of 323.5 MHz with a height of the tuning plates of 6.5 mm without an dipole field. This model is more robust concerning the dipole on parameter changes than type I and has still the possibility to lower the dipole through the stem cutting (see figure 6) or more stem width.

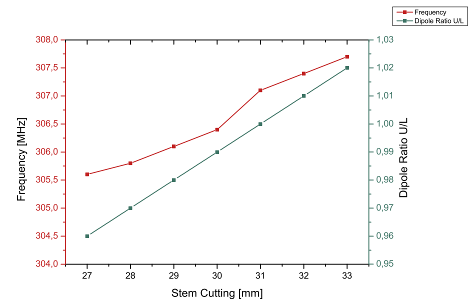

Figure 6: Frequency and dipole ratio of type II with different stem cuttings.

The simulations have shown that it is possible to apply the essential parameter settings for a 325 MHz RFQ on the present state of 4-Rod design. This means that the frequency can be reached with no disturbing dipole field besides an overall fitting field geometry. A frequency adjustment can be done using the tuning plates. Now these achievements need to be verified by building a prototype of this structure.

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