DEVELOPMENT OF A 325 MHz 4-ROD RFQ*

B. Koubek, J. Schmidt, U. Bartz, A. Schempp
IAP, Goethe University, Frankfurt am Main, Germany

Abstract

A 4-Rod Radio Frequency Quadrupole (RFQ) with a frequency of 325 MHz and an output energy of 3 MeV will be build as a part of the FAIR project of GSI. Design studies and model measurements on a short prototype of a 325 MHz 4-Rod RFQ model were made including simulations using CST Microwave Studio®. The latest simulation results regarding the dipole field of this structure are presented in this paper.

INTRODUCTION

4-Rod RFQ structures are usually built for frequencies up to 200 MHz. 325 MHz is a atypically high frequency for a 4-ROD structure. For this high frequencies usually 4-VANE RFQs are used. On the other side 4-Rod structures are cheaper, easier to build and comfortable for maintenance. So it would be desirable to have a 4-Rod RFQ for higher frequencies.

By reducing the size of a 4-Rod RFQ to fit a frequency above 300 MHz a several challenges occur to be solved. One effect that occurs is a electrical dipole field overlaying the quadrupole field of the electrodes. If this dipole field is not removed a lowering of the beamline along the structure is the consequence.

To research this effect fundamentally simulations with CST Microwave Studio® have been made on a simple RFQ model adapted to 325 MHz. The influences on the resonance frequency f_0, the quality factor Q and the normalized shunt impedance R_{pL} due to different parametric changes on this model have been investigated and are presented in the following.

SIMULATIONS

Variations of the Stem Shape

A 4-ROD RFQ can be described as a chain of $\frac{\lambda}{4}$ resonators that are operated in π-0-mode (figure 1). Its structure works as a capacitive loaded line where the electrodes represent the capacity and the stems the inductivity. Adjacent electrodes have opposite voltages forming the quadrupole field.

For high frequency and hence geometrically smaller structures an undesired dipole field occurs because of a increased charge transportation to the upper electrodes in comparison to the lower ones. The stems of an RFQ can be described as lecher wires and hence current and voltage distribution is depending on the height of the stems. The

* Work supported by BMBF

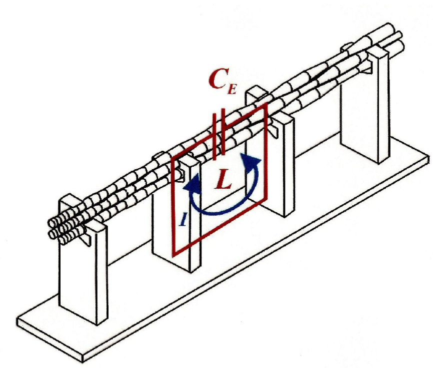

Figure 1: Basic cell of a 4-ROD RFQ structure.

different height of the upper and lower electrodes has only a small effect on larger and therefore low frequency structures. With higher frequencies and smaller dimensions one has to take account of this relatively more intense effect.

The RFQ model used for simulations is characterized by the basic parameters in Table 1.

Table 1: Margin Specifications of the Simulation Structure

325 MHz 4-ROD RFQ	
Beam Axis Height	83.5 mm
Stem Distance	47.64 mm
Stem Thickness	10 mm
Aperture	5 mm
Electrode Radius	3.5 mm
Length of the Structure	27.2 cm
Number of Stems	6

To reduce the dipole field several stems shapes have been simulated. Three important variations are shown in figure 2. This variations have been executed step by step to be able to plot the behaviour of the resulting field. The dipole field has been investigated by comparison of the voltage distribution along the structure of the upper and lower electrodes.

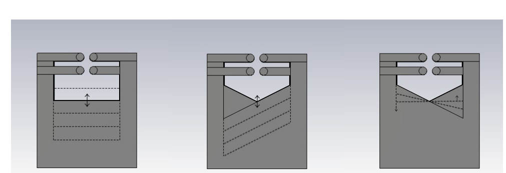

Figure 2: Variations of the stem shapes to eliminate the disturbing dipole field.

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)

Dipole Field

The graph shown in figure 3 demonstrates the straight cutting of a stem. There is no compensation of the dipole field. Unlike on regarding figure 4 and 5 one can find that the voltages of the higher and the lower electrodes are converging to each other due to the angle of the cutting. On a certain point the voltages are completely adjusted and the dipole field is eliminated. It is possible that this effect is even overcompensating. This behaviour is special for this geometrical small and high frequency structure and shows that it is possible to adjust the dipole field completely.

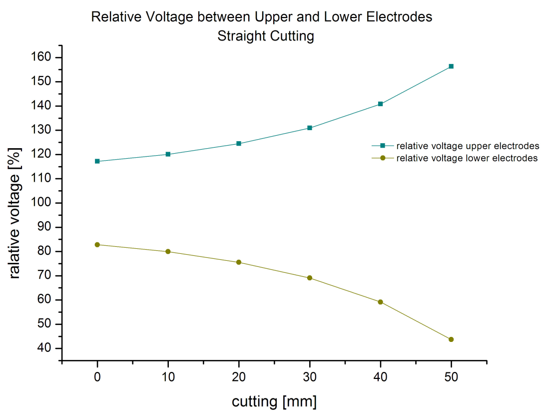

Figure 3: Voltages of the upper an lower electrodes on the straight cutting.

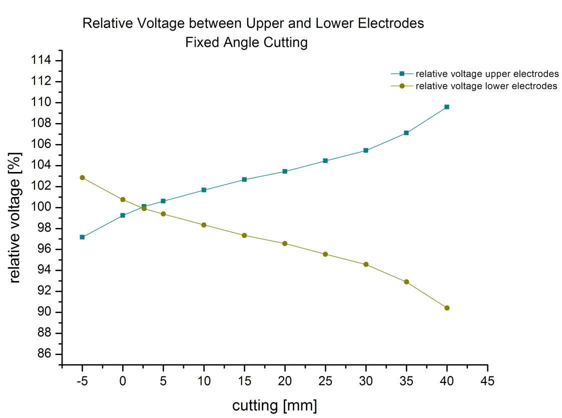

Figure 4: Adjusting and overcompensating of the dipole field on the fixed angle cutting.

The effect of the angular cutting on the dipole field is constant along the whole structure. This behaviour is shown in figure 6. The right picture shows that the upper electrodes are supplied with more charges so the voltage is higher than on the lower ones. The brighter blue on the left picture indicates the compensation of the dipole field.

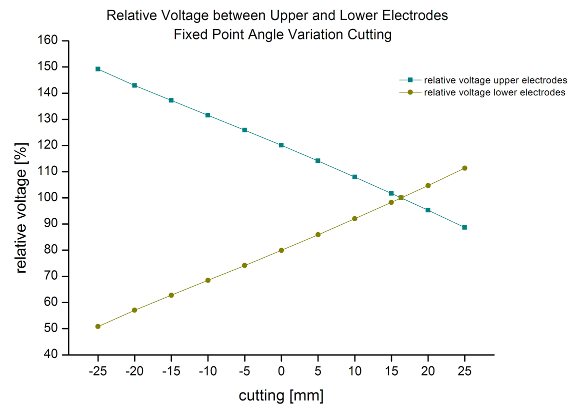

Figure 5: Adjusting and overcompensating of the dipole field on the fixed point angle variation cutting.

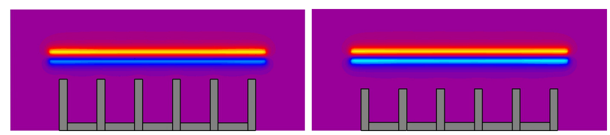

Figure 6: Electric field on the electrodes along the beamline at 20 mm (left) and 45 mm (right) angular cutting of the stems.

In figure 7 the electric field of two angular cuttings is demonstrated. One can see that the electric field surrounding the beamline is of better symmetry with the optimal cutting and hence there is no lowering of the beamline anymore.

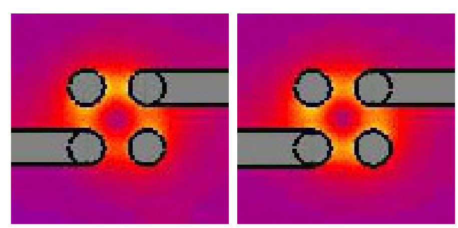

Figure 7: 20 mm (left) and 45 mm (right) angular cutting of a stem. The homogeneous color between the electrodes in the right picture shows the equal voltage distribution between all electrodes.

This adaption of the upper and lower average voltage relies on increased charge transportation to the lower electrodes caused by the magnetic field surrounding the arms of a stem. As a result of the angular cutting, there is more space for the magnetic field on one side of the stem what is illustrated in figure 8.

It is necessary to take the deeper cutting on the side of the stem with less charge and hence less voltage. This is appropriate for the side with the lower electrodes. By providing more space the inductivity rises and more charge accumulates at the electrodes. As result the imbalance of the field is compensated. Simultaneously the resonant fre-

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)

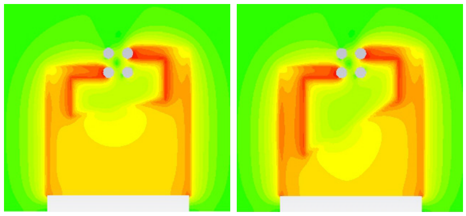

Figure 8: Magnetic field of different angular cuttings of a stem. The magnetic field surrounds the whole arm of a stem. Due to the cutting the magnetic field rises.

quency drops slightly by increasing the inductivity. To find a appropriate adjustment one has to regard some other resonator values.

Influences on Other Parameters

Table 2 shows the variation of an angular cutting of different height (middle picture in figure 2) and the corresponding shunt impedance and quality factor.

Table 2: Resonant Values of an Angular Cutting

Cutting [mm]	$\mathbf{f_0}$ **[MHz]**	$\mathbf{Q_0}$	$\mathbf{R_{pL}}$ **[kΩm]**
10	329.0	4332	69
20	326.9	4313	70
30	324.6	4282	71
40	322.3	4242	71
45	321.0	4220	70
50	319.6	4200	71

The resonance frequency drops with increasing the cutting depth. On taking a look at the quality factor and the shunt impedance one can see that those parameters stay nearly constant. There is a noticeable trend of decrease of the quality factor but in this range it is negligible for a real structure. For a later tuning of a real structure too high tuning plates would degrade the quality factor and shunt impedance thus one has to avoid too drastic variations of this plates.

CONCLUSION

The simulations show an elimination of the dipole field on a ratio of the stem side length from the higher to the lower stem side of approximate 2 and an angle of the cutting between 25° and 30°. The deeper the cutting the steeper the angle needs to be to equal the voltage causing the dipole field. This means a deeper cutting leads to higher voltage of the lower electrodes caused by a higher inductivity. This needs to be balanced by a larger ratio of the left and right cutting. The inductivity needs to be adjusted according to the cutting depth. The choice of the cutting and its steepness strongly depends on the resonance frequency. A higher resonance frequency leads to a more sensitive RFQ concerning changes of the stem shape so it needs to be adjusted to each RFQ in particular to every changes made on other parameters of a structure.

REFERENCES

[1] A. Schempp, "Overview Of Recent RFQ Projects", Proceeding LINAC 2008, Victoria, Canada

[2] L. Groening, W. Barth, L. Dahl, R. Hollinger, P. Spädtke, W. Vinzenz, S. Yaramishev*, GSI, Darmstadt, Germany; B. Hofmann, Z. Li, U. Ratzinger, A. Schempp, R Tiede, Johann Wolfgang Goethe University, Frankfurt a.M., Germany, "A Dedicated 70 MeV Proton Linac for the Antiproton Physics Program of the Future Facility for Antiproton And Ion Research (FAIR) at Darmstadt", LINAC 2004, Lübeck, Germany

[3] B. Hofmann, L. Brendel, A. Schempp, "Design of a 352 MHz-Proton-RFQ for GSI", LINAC 2004, Lübeck, Germany

[4] L. Groening, W. Barth, G. Clemente, H.-L. Dambowy, H. Podlech, U. Ratzinger, G. Schreiber, W. Vinzenz, "Status of the FAIR Proton Linac", GSI Scientific Report 2008

[5] B. Hofmann, "Untersuchungen an einem RFQ-Beschleuniger für hohe Betriebsfrequenzen", Diploma Thesis June 2004, Goethe University, Frankfurt

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)