STATUS OF THE 325 MHz 4-ROD RFQ*

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Abstract

For the FAIR project at GSI as part of the proton linac a 325 MHz 4-ROD RFQ with an output energy of 3 MeV is planned[1][2]. Due to the simulations regarding the RF design a prototype of this RFQ was built. Measurements on this prototype to verify the simulation results have been done. In addition simulations with increasing cell numbers and simulations concerning the boundary fields of the electrodes are presented in this paper.

PROTOTYPE

Design

After simulations regarding the dipole field [3] and frequency by changing several parameters [4] that have influences on the RF behaviour of the structure, a prototype has been built. Figure 1 shows that prototype and its simulation model.

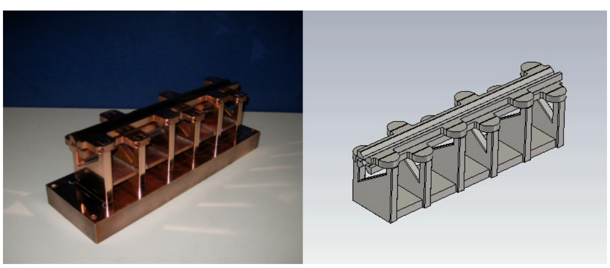

Figure 1: Prototype and Simulation Model.

The prototype is completely made of copper and has a water-cooled ground plate for power testing. The parameters of the prototype and the simulation model are shown in Table 1.

Table 1: 325 MHz RFQ Parameter

Parameter	Prototype	Simulation
Beam Line Position [mm]	65	59
Stem Width [mm]	63	63
Stem Distance [mm]	50	50
Mean Aperture [mm]	2.9	3.225
Electrode Tip Radius [mm]	2.5	2.5
Clamp Height [mm]	8	8
Clamp Broadness [mm]	26	
Clamp Radius [mm]		13
Width of Stem Arm [mm]	10	10

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There are slight differences at the clamps that are fixing the electrodes to the stems due to machining reasons. These differences are shown in Figure 2.

The prototype was built with a higher beam line position to have greater tuning possibilities to adjust the frequency. With a tuning plate hight of 6 mm the beam line is like the one in the simulations.

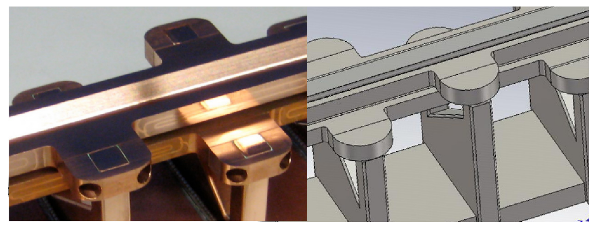

Figure 2: Different clamps of the prototype and the simulation model.

RF Measurements and Tuning

Several RF measurements on the Prototype have been executed and compared with the simulations. These measurements were concentrated on the frequency adjustment, the longitudinal voltage distribution along the electrodes, the so called flatness, and the dipole field. The results can be found in Table 2.

Table 2: RF Measurement Results

Parameter	Prototype	Simulation
Frequency		
Frequency at Beam Line Position 59 mm [MHz]	293.7	290.6
Tuning Range		
Tuning Plate min [MHz]	283.8	290.6
Tuning Plate max [MHz]	335.3	346.0
Tuning Plate Shift [mm]	20.2	18
Frequency Shift [MHz]	51.5	55.4
Dipole		
U/L TPh min	1.00	1.00
U/L TPh max	1.03	1.00

The dipole is given as the ratio of the voltage of the upper to the lower electrodes (U/L) and TPh means the tuning plate height which was changed for frequency adjustment.

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A 4-ROD RFQ can be described a a chain of $\lambda/4$-resonators. It is operated in π-0-mode to get opposite potential on the adjacent electrodes and a constant voltage along the RFQ. One basic cell can be described as a resonant circuit with its capacitance given by the electrodes and its inductivity given by the stems and the tuning plates.

In an untuned case the flatness of an RFQ without any modulation on the electrodes has a banana shape like one can see regarding Figure 3. This is because of the interaction of the single RF cells besides the electrode overlap causing more capacitance at the ends of the structure. On a closer look this curve has a sinuous sub shape. This shape results from the current flow causing a local maximum on the middle of two neighboring stems that are connected with the same electrode. A maximum voltage between the electrodes is generated in the middle of an RF cell. The dipole has a very small deviation on this structure even if the structure is untuned.

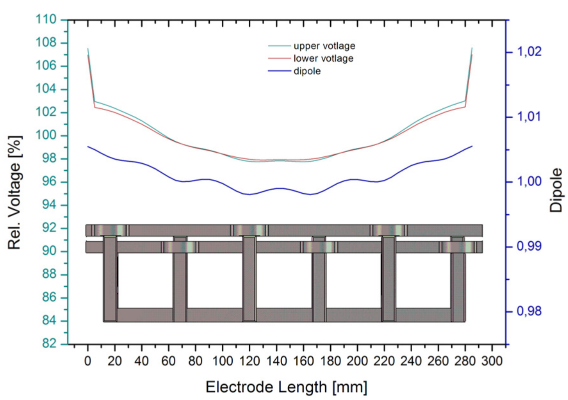

Figure 3: Flatness of the upper and lower electrodes and dipole along the electrodes.

For operation a homogenous voltage distribution of its electrodes is required according to the beam dynamics design. By changing the height of the tuning plates on the one hand the frequency and on the other the local eigenfrequency of a single cell can be adjusted. Hence an uneven voltage distribution, caused by the modulation of the electrodes or inaccuracies by manufacturing of the RFQ can be adjusted.

First measurements with all tuning plates at the same height have shown a frequency of 324.3 MHz and a difference of the longitudinal voltage distribution of ± 3.4 %. This structure is very sensitive on parameter variations. Each mm tuning plate shift can change the local eigenfrequency about 2 MHz. Nevertheless after adjusting of the tuning plates the difference of the voltage distribution of the electrodes was only 1.6 % (see Figure 4). In further tuning measurements eventually in addition with a piston tuner the flatness might be even improved.

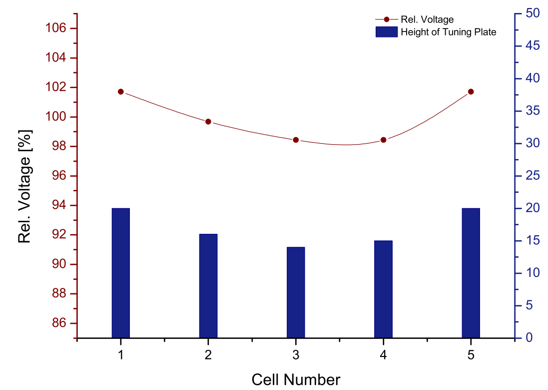

Figure 4: Relative longitudinal voltage distribution. The position of the tuning plates is displayed by the bars.

SIMULATIONS

Higher Order Modes

The electrodes of a 4-ROD RFQ are brought to the correct quadrupole potential by an arrangement of quarter-wavelength transmission lines. In addition if all RF cells are at the same phase it is called the π-0-mode.

However besides the 0-mode higher order modes (HOM) occur as well. These modes are not desired because they are not useful for acceleration. In 0-mode the field distribution along the electrodes is constant. HOM causing an irregular longitudinal voltage distribution on the electrodes. The number of the single rf-cells (N) is giving the number of HOM. The first HOM is called the $\frac{1}{N}$-π-0-mode and causes one node in the middle of the electrodes (see Figure 5) . In the highest mode the potential along the electrodes changes on every single rf-cell and would be called the π-mode.

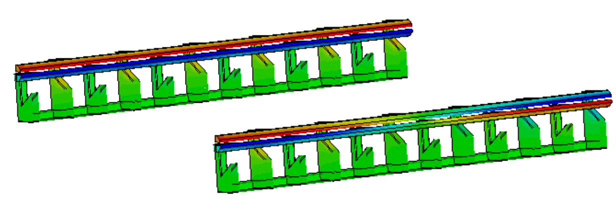

Figure 5: Voltage distribution of the 1st and 2nd mode of a 4-ROD RFQ.

The frequencies of the HOM are given by the amount of the coupled cells. In Figure 6 one can see the frequency of the modes according to electrode length and stem respectively cell number.

In these simulations the number of stems and coincidental the length of the electrodes was enhanced. In this process the first three modes were observed. One can see that the frequencies of these three modes converge to each other with rising stem numbers.

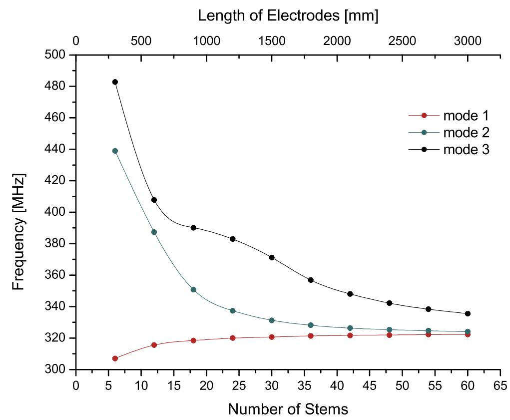

Figure 6: 1st, 2nd and 3rd mode of the RFQ with increasing number of stems and electrode length.

The frequency of the fundamental mode rises slightly till it goes into saturation. The frequencies of the second and third mode are decreasing and converging to the fundamental mode. At an electrode length of 2985 mm and 60 stems the second mode with 324.1 MHz is 1.8 MHz above the fundamental mode with 322.3 MHz. These modes are quite close to each other but simulations have shown that it is possible to influence this distance by the tuning plates configuration. How much these modes can be separated will be researched in further simulations.

Boundary Fields

The overlap of the electrodes has not only an influence on the voltage distribution along the electrodes but also on the voltage between the electrodes at the wall of the cavity. An ideal overlap would have the half length of an RF-cell but this would cause an overlap of 1.5 RF-cells on the electrodes fixed on the second stem (loose electrodes). So usually the overlap is meant to be $1/4$ of an RF-cell [5] (see Figure 7).

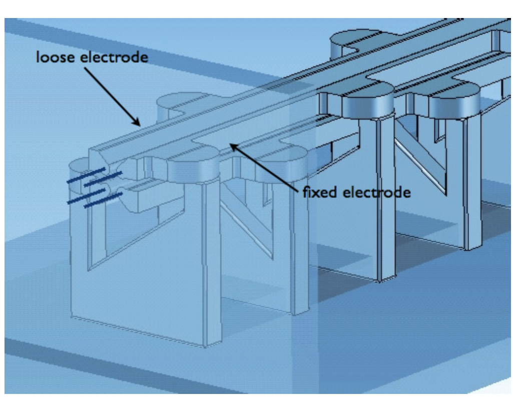

Figure 7: Fixed and loose electrodes and lines showing the distance between electrodes and cavity wall.

The electrodes fixed on the first stem (fixed electrodes) usually have a lower voltage against the cavity wall in comparison to the loose electrodes. Simulations changing the distance from the electrodes to the cavity wall have shown that a greater distance rises the voltage of the fixed electrodes in relation to the loose ones but with decreasing rates compared to greater distance.

The best distance between electrodes and the cavity wall would be between 5 and 15 mm to avoid unnecessary drift distance for particles. The distance of the 325 MHz prototype was chosen to be 7 mm.

CONCLUSION

A 325 MHz 4-ROD RFQ prototype with 6 stems was built. First RF measurements regarding the dipole field and flatness have been executed and show good accordance with the simulations. The next steps will be vacuum and power tests with this prototype. Furthermore simulations regarding the length of the RFQ and the separation of the higher order modes will be executed.

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