SIMULATIONS OF THE INFLUENCE OF 4-ROD RFQ ELEMENTS ON ITS VOLTAGE DISTRIBUTION *

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Abstract

The influence of tuning methods and other design elements of 4-rod RFQs on the voltage distribution have been studied during the last months. Every change in the field geometry or the voltage distribution could for example lead to particle losses or a raise in the surface current on single parts of the RFQ. That is why further research has to be done about the behavior of the 4-rod RFQ especially in the comparison of structures at 100 or 200 MHz. The results of an analysis which is concentrated on simulations using CST MicrowaveStudio to evaluate the effects of the overlap of electrodes, modulation and piston tuners on the fields in the RFQ are presented in this paper.

FLATNESS

A 4-rod RFQ consists of a chain of $\lambda/4$-resonators. A simplified model of the resonator is a chain of LC oscillators with the electrodes corresponding to the capacitance, while the inductance is given by the current path along the stems and the ground plate or tuning plate (compare Fig. 1). A more detailed model is described in [4].

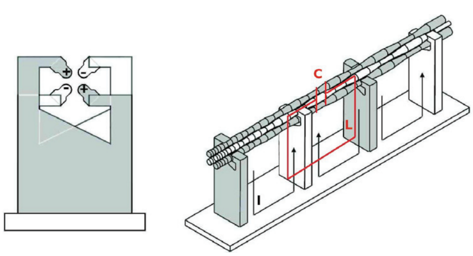

Figure 1: 4-rod RFQ as a LC oscillator.

In the ideal case each of these circuits resonates at the same frequency f_0. But due to differences in the modulation design or for example small defects in fabrication, usually there exists a small tune shift between all of the RF cells.

Corresponding to the differences in the resonance frequency of the single RF cells, there occurs a deviation in the voltage distribution compared to its normal operation mode. The RFQ is operated in its fundamental mode, meaning the 0-mode with a designed constant voltage along the electrodes. Differences in the longitudinal voltage distribution, the so called flatness, can lead to particle losses or at least a higher power consumption of the RFQ, which can cause for example problems in the cooling of single parts of the structure.

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In this paper the influences of different components of the RFQ on the flatness will be discussed in detail.

Tuning Plates

To manipulate the deviations from cell to cell in the longitudinal voltage distribution of the electrodes short cut plates are used. These so called tuning plates variate the current path in an RF cell, so that the inductance of this cell is changed. By that following the Thomson formula $f_0 = 1/\sqrt{LC}$ the resonance of that cell is changed, what results in a lowering of the voltage in that and the neighboring cells. This effect is plotted in Fig. 2 with a varied insertion hight of the plate from 0 mm up to 55 mm.

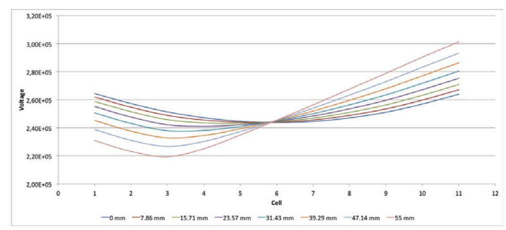

Figure 2: Variation of the tuning plates height.

OVERLAP OF ELECTRODES

Speaking about a not constant voltage along the electrodes their overlap is one of the dominating factors. Due to the additional part of the electrodes influencing the boundary RF cells, their frequency is lowered compared to the mid cells of the RFQ. That deviation leads to a higher voltage in these cells, what is reflected in the typical tub like shape of the flatness.

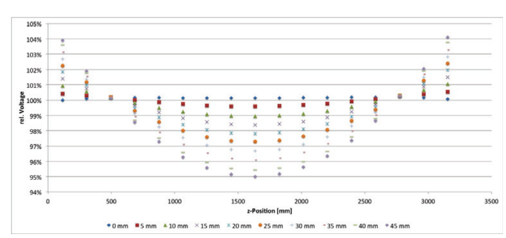

Figure 3: Variation of overlap in a 3-m RFQ at 100 MHz.

Fig. 3 and Fig. 4 show the changes in flatness caused by a growing overlap in two different RFQ models. One is a 3 m long RFQ with a resonance at about 100 MHz and the other one is a high frequency RFQ at about 200 MHz with a length of 1 m. Both structures show a similar building of the typical tab form, while the 200 MHz

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RFQ reacts a bit more sensitive with a maximal difference of 10 % between the highest and the lowest voltage.

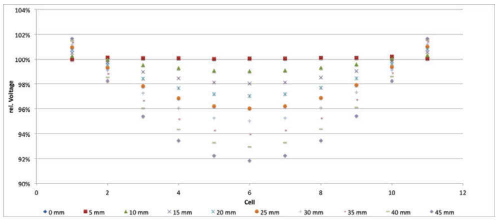

Figure 4: Overlap variation in a 1 m long 200-MHz RFQ.

Drift Tube

Another component, which is interesting because of its influence on the voltage of the electrodes with respect to the tank wall, are inserts at the RFQs entrance and end. Their effect on the beam can be compared with a drift tube, which has been analyzed with varying diameters of the drift tube, as shown in Fig. 5.

The drift tube is connected to an insert in the end wall of the RFQ on its high energy end. It causes a reduction of the electrode ends voltage, so that it has a positive a effect on the flatness. This effect is similar for different diameters of the drift tube, as all curves lie close to each other.

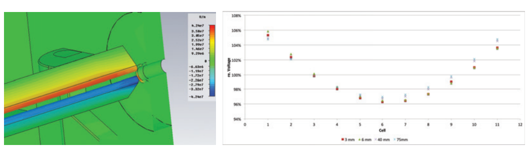

Figure 5: Simulation of a drfft tube at high energy end.

STEM DISTANCE

The second parameter to define the resonance frequency is the inductance of the RF cell. It is defined by the current path over the stems, the tuning plates and the electrodes. Concentrating on that influence on the flatness, the distance of the stems was swept from a value of 100 mm down to half the width, meaning a resonance shift of nearly 110 MHz from 150 MHz to 258 MHz. Taking the 50 mm stem width as a reference of 100% voltage, it is especially clear, that the low frequency structure reacts less sensitive, as the deviation in flatness is much smaller while its magnitude is reduced, too.

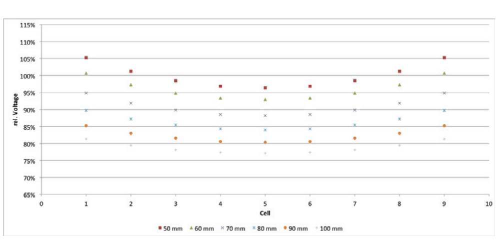

Figure 6: Variation of stem distance.

MODULATION

In most 4-rod RFQs the only not symmetric factor, which distinguishes one RF cell from the others is the modulation profile of the vanes. In the low energy section of the RFQ the modulation is close to one, so that there is only a small sine profile visible on the vanes. Moving on to the high energy end and the acceleration part, that profile becomes more significant.

In Fig. 7 the simulation model of a 200 MHz RFQ with modulation is presented. While the electrodes keep their constant charge, the alternation of the electric field on the beam axis with every acceleration cell is obvious. The resonance frequency and quality factor of RFQs can be simulated quite accurate including the modulation profile of the vanes.

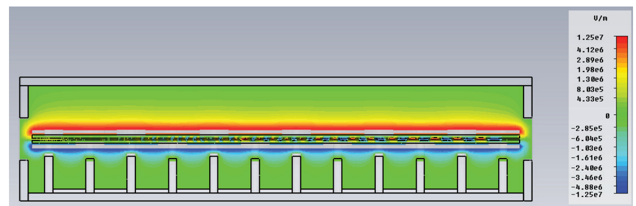

Figure 7: Alternating electric field between modulated electrodes.

Looking at the flatness, the simulation results with and without modulated electrodes are presented in Fig. 8 in comparison with the corresponding measurements. The simulation without modulation reflects the degree of the deviation from a constant voltage, but is not including the asymmetric influences in the RFQ. The modulated curve shows a totally different behavior, which can not be seen in any correlation with the measurement. It seems like this fine detailed reproduction of the electrodes leads to problems in the meshing or other requirements in the simulation.

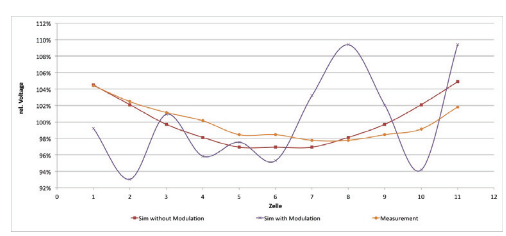

Figure 8: Simulated flatness with and without modulated electrodes in comparison to measurement.

TUNING COMPONENTS

There are several tuning methods used in the RFQ except of tuning plates. The most common one are piston tuners, which are used to tune the resonance frequency of a 4-rod RFQ during operation. A shift in the resonance of an operated RFQ in the order of hundreds of kHz can be caused by effects like vacuum, heating, beam loading or others.

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This tuner is a resonator in itself, so in the design it is important to check its eigenmodes in comparison to the operation frequency of the RFQ. Inducing a resonance in the tuner can lead to heating and in worst case even to melting of the components of the tuner.

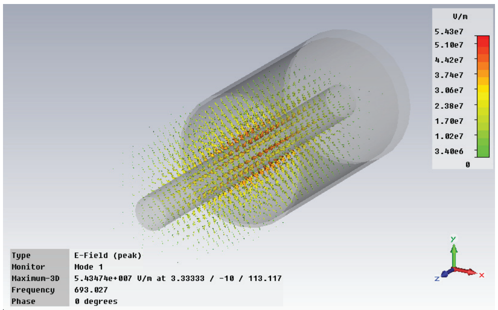

Figure 9: Electric field simulation of the piston tuner

Depending on the length of the structure there are typically one or two piston tuners in use, like in the two showcase structures presented in Fig. 10 and 11. Here the offset of the flatness on the upper and lower electrodes is illustrated.

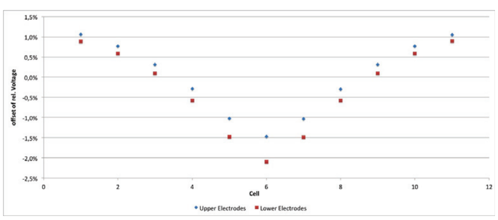

Figure 10: Offset in flatness with and without tuner on the upper and lower electrodes at 200 MHz.

Here it is interesting to see, that the insertion of the tuner can effect the electrodes voltage in both ways of increasing and decreasing. The reaction of the RFQ structure to the suppression of the magnetic field in an RF cell depends on the individual characteristic. In one case the capacitive in the other case the inductive impact of the tuner seems to be dominating.

Because of the tuners geometric position between the stems, in both cases the effect on the voltage of the lower electrodes is higher than on the upper pair.

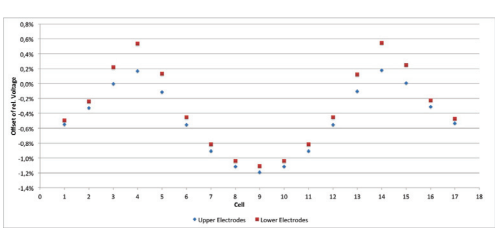

Figure 11: Offset in flatness with and without tuner on the upper and lower electrodes at 100 MHz.

SUMMARY

In this paper the effects of different components in 4-rod RFQs on its longitudinal voltage distribution, the so called flatness, are analyzed.

Looking at the different effects, it becomes clear that it is important to consider all the influences of every component in the RFQ. They all add up to result in a really unique distribution one has to deal with in the design and RF setup of an 4-rod RFQ. As the simulations of modulated electrodes reveal, it is still difficult to predict a flatness of an RFQ before manufacturing.

A carefully prepared tuning setup of an RFQ has to be a combination of simulations and measurements, which can lead to a better performance of 4-rod RFQs in operation.

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