

SIMULATIONS ON THE BOUNDARY FIELDS OF 4-ROD RFQ ELECTRODES*

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Abstract

If the RF design of a 4-rod Radio Frequency Quadrupole (RFQ) is not performed carefully with respect to the boundary fields of its electrodes, it can produce errors compared to beam dynamic simulations. An additional field component can be induced on the beam axis, which influences the properties of the particle beam, like energy per nucleon for example, dramatically. Therefore, the influences of different geometric parameters of 4-rod RFQs on these fields have been studied in detail. The results of these simulations will be presented in this paper.

THE 4-ROD RFQ RESONANT CIRCUIT

The RFQ is a linear accelerator which is used in the low energy section just following the ion source in many projects [1]. There are several concepts for its construction, the 4-vane and the 4-rod RFQs are the most common principles [2]. In Fig.1 the resonator fields of both RFQs in their operation mode are presented. The main difference is while the 4-rod is a current resonator, where the fields are concentrated around the structure, the 4-vane is a cavity resonator completely filled with fields and current on the cavity walls.

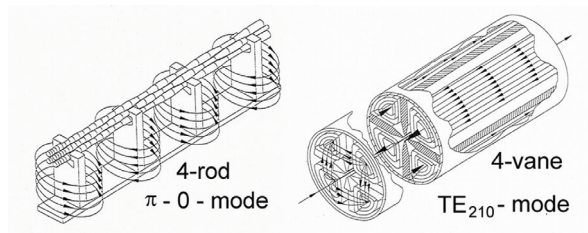


Figure 1: Field distribution of the operation modes of a 4-rod and 4-vane RFQ structure.

A chain of $\lambda/4$ -resonators represent the 4-rod resonance structure [3]. One RF cell can be described by a LC circuit, with the electrodes as the capacitance C and the stems with the ground plate as the inductance L. This circuit helps to understand the principles of tuning methods like short cut plates between the stems (see Fig. 3 right). They change the inductance of a cell as they are raised.

The magnetic field around the stems induce the currents to load the electrodes to two opposite potentials, which forms the quadrupole field to accelerate, bunch and focus the ion beam. A simulation model with the loaded electrodes is shown in Fig.2. All the RF simulations are performed using CST Microwave Studio ®.

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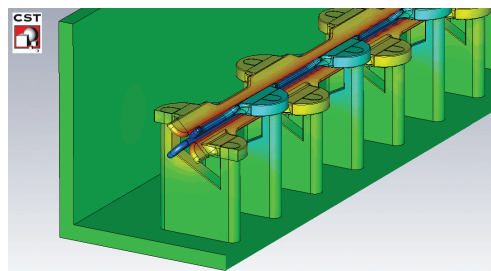


Figure 2: Normal electric field on the electrodes.

THE BOUNDARY SETTING OF A 4-ROD STRUCTURE

In many projects the size of the RFQ cavity is preset by the space available for the structure in the whole accelerator complex. The lack of space leads to the need of structures as short as possible [4]. In addition due to particle dynamics, one tries to avoid drift of the beam especially in the low energy part of accelerators, where defocusing of the beam is strong. This leads to cavity walls which are really close to the resonant structure. An example for this end section of two 4-rod RFQs is shown in Fig. 3.

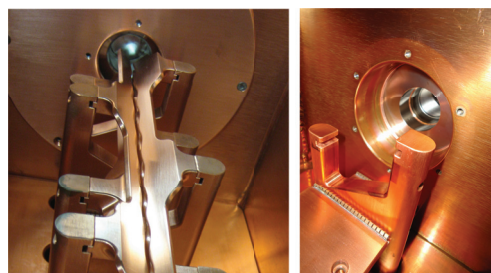


Figure 3: Pictures of the last RF cell in typical 4-rod RFQs. Examples of the Med-Austron RFQ (left) and the FNAL-RFQ with a tuning plate in the highest possible position (right).

Because of this tight situation at the boundaries, there is the only point in the RFQ where significant currents can be induced on the cavity wall. This is a well studied effect, which led to cooling in these walls for high duty cycle RFQs [5].

Looking at the field distribution there are the magnetic field lines surrounding the last stem, but there is also the electric fringe field of the electrodes reaching into the boundaries of the cavity as one can see in Fig.4. So there is a strong impact of their design on these fields.

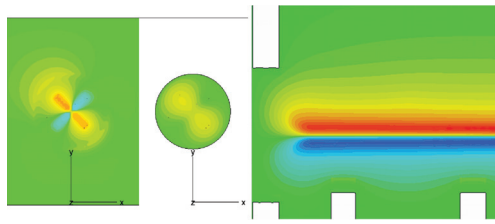


Figure 4: Fringe Fields. Amplified view of the normal electric field in the boundaries of a 4-rod cavity. The quadrupole field changes to a dipole far field.

FRINGE FIELD SIMULATIONS

In order to analyze the influence of the boundaries on the fringe field of the 4-rod RFQ mainly the geometric parameter of the electrodes overlap behind the last stem and distances to the cavity wall have been varied (see Fig. 5). Two other studied parameter are the height of the last tuning plate and the opening size of the end flange. To quantify the effects the induced change of the electric field component in the acceleration direction (E_z) in the gap between the cavity wall and the electrodes was observed.

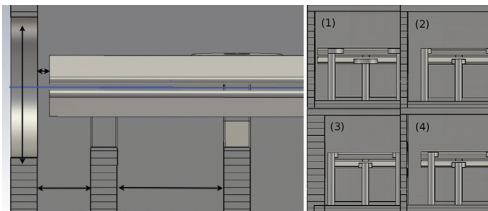


Figure 5: Geometric variation parameter for simulation of the boundary geometry influence in general (left) and the four geometric cases of the simulations presented in Fig.6 (right).

Overlap and Boundary Geometry

The results of the overlap geometry simulations are presented in Fig.6. The black curve (case 1) represents the regular proportions of the electrodes overlap to the cavity wall and the last stem. Cutting the overlap, so that the electrodes end with the edge of the last stem (case 2) leads to a reduction of E_z in the gap, which is even stronger, if the last stem is moved closer to the second last stem (case 4). This effect is canceled out, if the thickness of the cavity wall is increased, so that there is no overlap, but the distance to the wall is kept constant (case 3). Fig. 5 shows all these cases geometrically on the right.

Tuning Plates

In addition the effect of the height of the last tuning plate was studied. In a conventional 4-rod RFQ the last RF cells need to have the strongest tuning of all cells, because they carry a higher capacitance compared to the middle cells [6]. Fig. 7 shows the gap field E_z with the last tuning plate on the bottom (in black) and raised to its maximum position

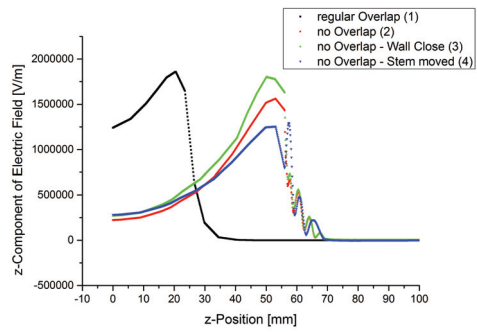


Figure 6: Results of the overlap geometric simulations. By optimizing the geometry the peak of E_z can be reduced by a factor of 1.5 nearly.

(red) like one can see in Fig. 3 right. The field is growing significantly with raising the plate.

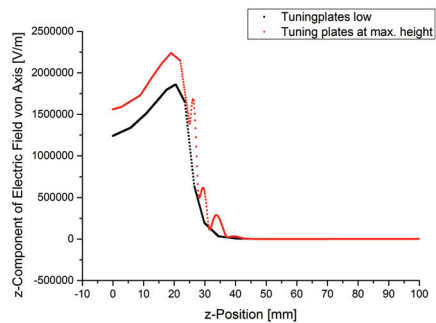


Figure 7: The influence of the tuning plates. Raising the tuning plate in the last RF cell to its maximum position induces additional field on the gap to the cavity wall.

End Flange

The last parameter variation which was studied is the opening size of the end flange (see Fig.9 for the geometric situation). The simulation results are presented in Fig.8. Here the radius of a round hole in the cavity wall was varied from 3 mm (black) to 6 mm (red) up to a huge opening of 40 mm (green) and 75 mm (blue). The radii of 40 and 75 mm have similar maximal E_z values in the gap as the results of the overlap variations. But closing the opening induces a peak field in the gap which is nearly a factor of 5 higher. Comparing the integral of E_z in the gap shows an increase of about 25% in this cases.

OPTIMIZATION OF THE 4-ROD RFQ WITH RESPECT TO ITS BOUNDARY FIELDS

The simulations on the influence of several RFQ parameter show, that there are some points to take care of in the design process of an RFQ. The key aspect is to give as much space as possible to the magnetic field around the

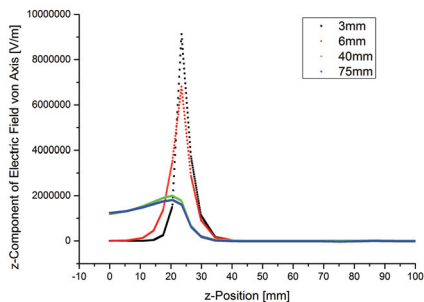


Figure 8: The influence of the end flange size. The strongest effect on the fringe field is clearly the design of the RF shielding at the end flanges of the RFQ with variation in the peak of E_z of a factor of 5.

last stems and the electric boundary field of the electrodes. A secondary effect is, that all other components which influence the field distribution of the RFQ, like tuning plates, should be at a minimum at the ends of the structure.

In the future design of 4-rod RFQs the RF shielding which defines the opening of the cavity at the ends of an RFQ will have an aperture as big as possible as pictured in Fig.9 and its distance to the electrodes will be increased compared to conventional designs.

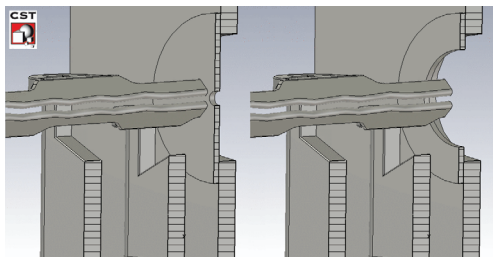


Figure 9: The RF shielding at the entrance and exit of the RFQ. To minimize fringe fields it should influence the RFQ fields as little as possible. This leads to a big opening and distance to the electrodes.

An other point is to find ways to reduce the need for tuning of the longitudinal voltage distribution (flatness) in the last RF cells. One idea to realize that is by fitting the length of the outer RF cells to compensate their extra capacitance. The results of flatness simulations with varied stem distances in the last RF cells is presented in Fig.10 in different cases. The black curve with a variation in the flatness of 26% corresponds to a conventional 4-rod design. This variation can be tuned with plates, but by reducing the length of the three outer RF cells by 5 mm (blue) it can be decreased to 4% in the simulations.

For every RFQ there is a optimum displacement of one or more outer stems which leads in addition to a reduced boundary field to an optimization of the flatness to a pre-defined profile. Using this option enables us to reduce the needed tuning and to shift it to regions along the structure

where their interaction with boundaries, the coupling loop or a piston tuner is minimized.

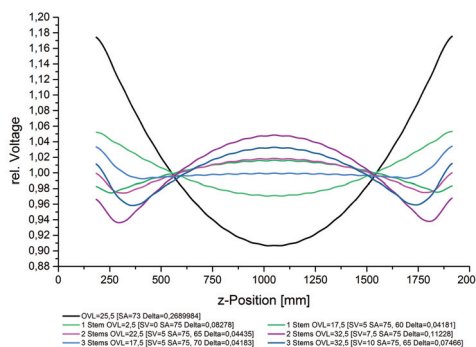


Figure 10: Variation of the stem distance in the outer RF cells. Compared to a conventional overlap of the electrodes an artificial overlap produced by a shift of the last stems towards the center of the RFQ reduces the fringe field and optimizes the field distribution along the whole structure.

CONCLUSION AND OUTLOOK

There is a strong influence of the mechanical boundaries like the overlap of the electrodes and its ratio to the space between the resonant structure and the cavity walls on the boundary fields of the 4-rod RFQ. To analyze this dependencies and to quantify the effect of mechanical changes systematic variations of several parameter of the boundary structure have been performed. This simulations lead to a better understanding of the influences of the cavity and resonator design on the electric field distribution of the RF quadrupole. There are good possibilities to optimize the fringe fields in the gap between the electrodes and the cavity walls within the RF design process of the 4-rod RFQ. The next steps will be to simulate these fields with more detailed RFQ simulation models and its influence on particle dynamics will be studied with CST Particle Studio®. Discussions with manufacturers need to show which ideas are feasible and the simulations of varied stem distances will be compared with measurements.

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