STATUS AND OUTLOOK OF THE 325 MHz 4-ROD RFQ *

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Abstract

In order to built a Radio Frequency Quadrupole (RFQ) at 325 MHz for the FAIR proton linac, a 4-rod structure has been investigated. The RF design, especially the dipole and fringe fields and higher order modes, have been studied with simulations. A prototype has been built and power tested to verify the simulation results and investigate the high power performance. This paper summarizes the results of the research concerning the 325 MHz 4-rod RFQ and gives an overview about the next steps in this project.

INTRODUCTION

The highest frequency 4-rod RFQs are operating is at 216 MHz. An example is the MedAustron RFQ presented in [2]. At higher frequencies the asymmetries of the 4-rod structure may cause problems in the RF behavior. For example a dipole field overlaying the quadrupole field of the electrodes can lead to a vertical displacement of the beam axis. Usually this effect can be neglected, but it becomes relatively stronger on frequencies above 300 MHz. Also potential disturbing higher order modes (HOMs) need to be investigated at this frequency. In addition a general improvement of the performance of 4-rod RFQs can be achieved through investigations of the fringe fields. Based on these improvements a prototype was built and power tested. Eventually the 4-rod RFQ was compared to other RFQ resonators in terms of operation at 325 MHz.

SIMULATIONS

Dipole

The dipole field is a disturbing field overlaying the quadrupole field component and can shift the beam axis in vertical direction. This field is caused by asymmetries of the 4-rod structure. These asymmetries are resulting from the electrodes mounted at different heights. By comparing one RF cell of a 4-rod RFQ with capacitively shortened Lecher Wires in Fig. 1, the upper electrodes are loaded with to a larger potential than the lower ones. This effect becomes relatively more significant at higher frequencies and hence smaller stem sizes. The basic idea to suppress the dipole field is to align the current paths respectively the charge transport of the left and right side of each stem. This can be done by the stem shape to provide space that magnetic fields can be established and increase the charge transport at the appropriate side of the stem. In addition all other main parameters of 4-rod RFQs have been investigated to study their influence on the dipole field.

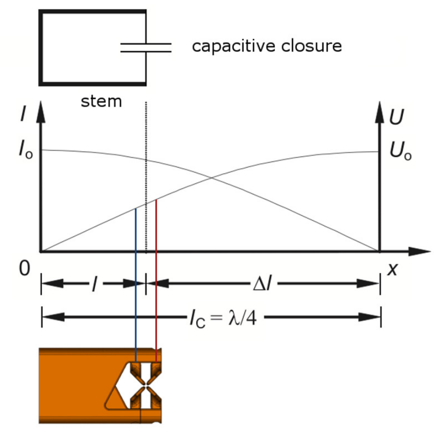

Figure 1: Comparison of a 4-rod RFQ with capacitively shortened Lecher wires.

As an example in Fig. 2 one variation of an angular cutting of the inner stem shape is shown. At one side of the stem the space sorrounding a stem arm is enlarged. The charge transport on the left and right side of the RFQ is balanced and leads to a compensation or even overcompensation of the dipole field. Several other ways of cutting variation were investigated in simulations [1]. Through this investigation a dipole free 4-rod RFQ could be designed and the results have been successfully proven with a prototype.

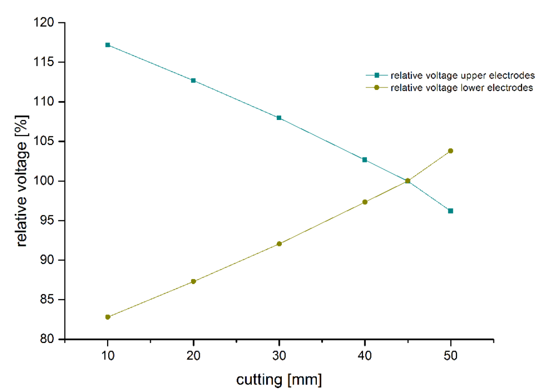

Figure 2: Adjustment and overcompensation of the dipole field by the variation of the angular cutting.

HOMs

If higher order modes (HOMs) are close to the operating modes frequency they might be excited as well and can disturb the operating mode. Usually HOMs are not critical

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at a 4-rod RFQ. But the frequency of 325 MHz and a length of the electrodes of about 3 m leads to a large number of RF cells. Because of this the frequencies of the HOMs are decreasing and converging to the operating frequency with an increasing number of RF cells. This is shown in Fig. 3 with simulations. The number of RF cells and the length of the electrodes respectively was increased up to the total length of about 3 m. This refers to a number in order of 50 to 60 RF cells.

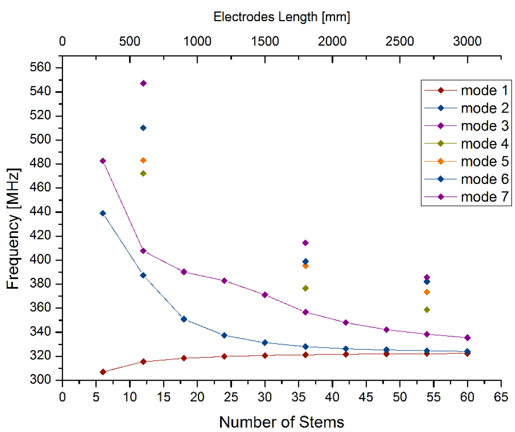

Figure 3: Simulation of the frequency of the higher order modes of a 325 MHz RFQ with increasing electrodes length and stem numbers.

At an electrode length of 2985 mm the difference between the fundamental and second mode is 1.8 MHz. This was not considered to be crucial, but needs to be observed. Simulations have shown that these modes can be influenced by the tuning plates if they get to a critical distance.

Fringe Fields

In order to optimize the performance of the RFQ an investigation and improvement of the fringe fields of a 4-rod RFQ was carried out. The intrinsic asymmetries of the 4-rod structure can cause a distortion of the boundary fields between the electrodes and the vessel wall. Such fringe fields can for example shift the beam axis at the end of the electrodes or deviate the particle beam energy. In order to minimize the electric field component in z-direction, several parameter settings of the RFQs' end geometry were investigated. These parameters were mainly the overlap of the electrodes, the distance between the electrodes and the last stem to the vessel wall and the aperture at the end flanges. Also investigations at the FNAL RFQs' beam output energy contributed to this topic [7]. This has shown that the fringe fields can cause a potential in the gap decelerating the beam and changing the beams output energy. To minimize the electric field between the electrodes and the vessel wall several parameters have been varied to investigate this fields. These variations are shown in Fig. 4.

A reason for the fringe fields are the asymmetric electrode mountings. Because two adjacent electrodes are connected

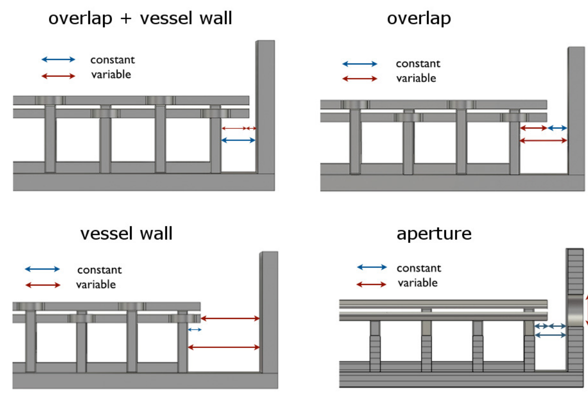

Figure 4: Variations of the boundary conditions for investigations of the fringe fields.

to the last stem and the other two electrodes are connected to the second last stem. This is leading to different current paths to the electrodes end. Simulations have shown that the surface current at the outer side of the last stem is less than for other stems, causing less current loading the electrodes mounted on the last stem. As results of these investigations to increase this current the crucial points are the reduction of the distance of the last stems, the enhancement of the space for the magnetic field around the last stem by larger spacing to the cavity wall and the positioning and aperture opening of the RF shielding respectively.

PROTOTYPE

To validate these findings a 6 stem copper prototype has been built and power tested. This short copper prototype is shown in Fig. 5. The low level RF measurements have

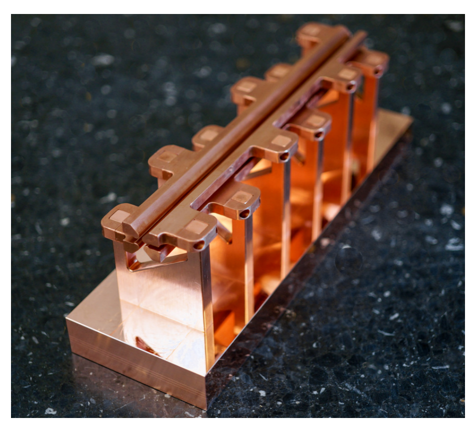

Figure 5: The 6 stem 325 MHz 4-rod copper prototype.

proven a good accordance to the simulation results with respect to the frequency and dipole simulations. After the RF setup of the prototype a deviation in the longitudinal voltage distribution of 0.02 % and a dipole of only 2 % could be achieved. The quality factor was about 2800 and the shunt impedance was determined to 54.6 $k\Omega m$ after an optimization of the prototype. The determination of the

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shunt impedance has been compared to different methods. These studies are presented in [3] and [6].

Power Tests

To demonstrate the RF performance of a 325 MHz 4-rod RFQ the prototype was power tested. After the low power conditioning up to 400 W cw power the prototype was power tested up to 40 kW at a duty cycle of 0.3 %. The FAIR proton linac will be operating at an even lower duty cycle of below 0.1% [8]. After an optimization of the prototype, which is described in more detail in [3], the RFQ was accepting 40 kW without difficulties. During these power tests the electrode voltage was measured, using gamma spectroscopy, at different power levels to determine the shunt impedance. Since the determination of the shunt impedance at low RF levels using a perturbation capacitance is defective at the prototype with a small electrodes capacitance, these measurements were compared to different methods of determination of the shunt impedance. These comparison is also presented more elaborative in [3].

COMPARISON

In order to operate at 325 MHz, different RFQ resonators have been compared in CST Microwave Studio simulations. Besides the 4-rod, a 4-vane, a Ladder and a CH RFQ have been considered. In these simulations the RF design and the tuning possibilities for frequency tuning and the setup for the longitudinal voltage distribution as well as dipole components were investigated. The CH RFQ gets unfeasible small dimensions at 325 MHz and was excluded. The others would be suitable opportunities to operate at the desired frequency without a dipole field. The Ladder RFQ is more complicated in engineering and the 4-vane is a more risky solution in order to meet the high accuracy requirements during machining and assembling the parts of the RFQ. The 4-rod RFQ meets all requirements with respect to the technological construction as well as the RF characteristics. In addition, due to the large experience in building 4-rod RFQs at the Goethe University Frankfurt, the 4-rod RFQ was regarded as the best solution to follow. The detailed results of this comparison are presented in [6].

OUTLOOK

The work presented in this paper has proven the feasibility of a 4-rod RFQ at 325 MHz to operate for the proton linac at FAIR. Further simulations on the dipole compensation are planned. In these simulations the stems are displaced to each other in left and right direction in relation to the beam axis. This shift provides an asymmetric connection to the electrodes and compensates the asymmetries of the current paths. Based on this investigations the best strategy to compensate the dipole will be decided. Due to the common RFQ length of 3 m the assembly will be a standard procedure. The electrodes are usually segmented at this length. The stems and the ground plate are supposed to be milled out of a solid copper block. This provides a higher accuracy of the machining besides a better thermal and electrical connection. Also a thermal extension of the material will be more homogenous avoiding local thermal stress on the structure. This ground plate and stem combination will be segmented as well due to machining reasons. A segment will end in the middle of one stem to ensure a good electrical connection on two half stems. Only a cooling of the stems is designated due to the low duty cycle. The RFQ tank is already in fabrication. As soon as the final construction is decided the remaining parts will follow.

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