TUNING STUDIES ON 4-ROD-RFQs*

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Abstract

For the optimization of Radio Frequency Quadrupole (RFQ) design parameters, a certain voltage distribution along the electrodes of an RFQ is assumed. Therefore an accurate tuning of the voltage distribution is very important for the beam dynamic properties of an RFQ. A variation can lead to particle losses and reduced beam quality. Our electrode design usually implies a constant longitudinal voltage distribution. For its adjustment tuning plates are used between the stems of the 4-Rod RFQ. Their optimal positions can be found by an iterative process. To structure this tuning process simulations with a NI LabVIEW based Tuning Software and CST Microwave Studio® are performed and compared to measurements of the ReA3-RFQ of the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. The results of this studies are presented in this paper.

RFQ MODEL

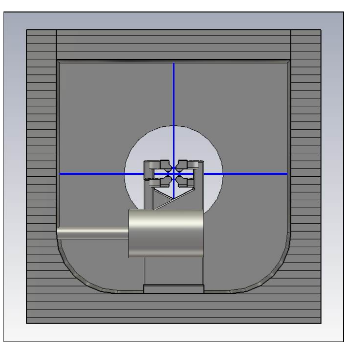

Figure 1: Cross section of the ReA3-RFQ Simulation Model.

The simulation model was based on the parameters of the ReA3-RFQ at MSU [2]. It consists of 18 stems with a total length of 3.5 m and has a resonance frequency of 80 MHz. Its geometry is summerised in the following table 1 and its shown in fig. 1, where the piston tuner is in its full range. By parametrization its position can be varied. The flatness simulations have been compared with measurements of the 4-Rod-RFQ, which was delivered in 2010 to NSCL. They have been performed by integrating the electric field over curves sitting on the field‘s maximum symmetrically arranged around the beam line (see fig. 2).

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Table 1: Geometric Parameters of the ReA3-RFQ

Parameter	Value
RF cells	17
stem thickness	20 mm
stem height	100 mm
stem distance	190 mm
tank diameter	390 mm (inside)
tank length	3.5 m
wall thickness	50 mm
beam height in tank	200 mm
tuner diameter	80 mm
electrode length	3.3 m

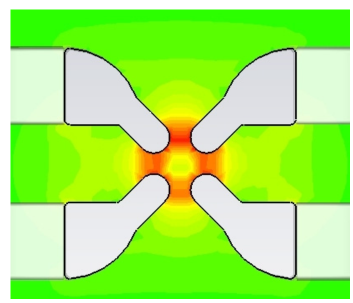

Figure 2: Quadrupole field between electrodes.

SYSTEMATIZATION OF THE TUNING PROCESS

A 4-Rod-RFQ consists of a chain of $\lambda/4$-resonators [4]. In the ideal case each of these circuits resonate at the same frequency f_0. But due to differences in the modulation design or for example small defects in fabrication, normally there exists a small tune shift between all of the rf cells.
Following the particle dynamics the longitudinal voltage distribution has to be arranged. For this tuning process short cut plates are used. They are positioned between the stems and by adjusting their height, it is possible to tune the inductivity of a rf cell. This change allows an arrangement of the resonance frequency ω_0 following the Thomson formula.

$$\omega_0 = \frac{1}{\sqrt{(L + \Delta L)C}} \tag{1}$$

Presently the tuning process of the longitudinal voltage distribution (flatness) of a 4-Rod RFQ is an iterative process [9]. Within one RFQ each rf cell reacts a bit differently to the same tuning step. In order to quantify this behaviour so called effect functions EC were introduced, describing the shift in flatness caused by a change in the postion of

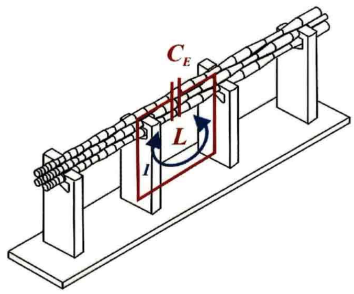

Figure 3: LC Resonator as Equivalent Circuit of a 4-Rod RFQ.

the tuning plate of each rf cell. They correspond to the ratio between the tuned and the untuned flatness. With this set of measurements it‘s possible to simulate the tuned flatness UF_T based on the untuned flatness UF_U and the effect functions EC.

$$UF_T(z,h) = UF_U(z) + EC(z,h) \times UF_U(z) \quad (2)$$

By changing the current path and with it the inductivity of the rf cell the voltage is decreased. In a certain range this effect is linearly dependent to the height, which leads to the following equation for the tuned flatness UF_T [8].

$$UF_T(z,h) = UF_U(z) \times \prod_{k=1}^{N} [h_k \cdot EC_k(z) + 1] \quad (3)$$

This defect in the flatness can be simulated by CST MWS appropriately, while its hard to simulate the measured absolute distribution. In this example a tuning plate is inserted in cell no. four with a height of 25 mm. Fig. 4 presents the measured distribution, while fig. 5 shows the simulation results.

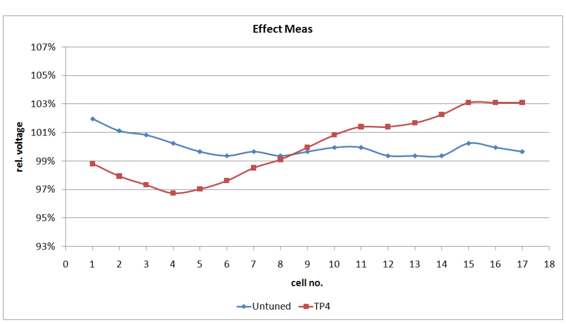

Figure 4: Measured Flatness of the ReA3-RFQ. In Blue the Untuned and in Red the Distribution With a Tuning Plate in Cell No. 4.

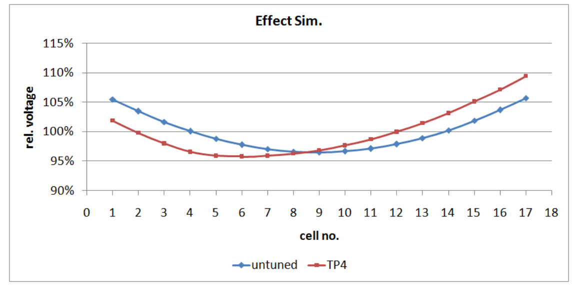

Figure 5: Simulated Flatness of the ReA3-RFQ (Same Case as in Fig. 4).

Status of the Tuning Program

The Tuning Program is an application to tune the flatness of an 4-Rod RFQ.

It should be possible to measure a fixed set of curves to import, so one can simulate the effect of changes in the position of every single tuning plate. Currently one has to measure the effect function EC for each rf cell using the perturbation capacitor method. These data can be imported to the program, where one can see the change in flatness caused by positioning a tuning plate directly. A interesting flatness result can also be exported together with its corresponding tuning plate distribution to be used in other applications.

In fig. 6 and 7 some results of the Tuning Program are compared to measurements of the ReA3-RFQ for different tuning plate distributions (TPV 1-3 and TPV 12). The height of the tuning plates in each rf cell is shown as a short bar. In the corresponding color the measured data (dots) and the result of the Tuning Program (lines) are plotted. The distribution for TPV 12 in graph 7 is also compared to the results using CST MWS to simulate the effect functions (blue graph). This distribution equates to the final tuning set up of the ReA3-RFQ. Especially for this small details in the flatness one can see the advantages of the measured ECs compared to the simulated.

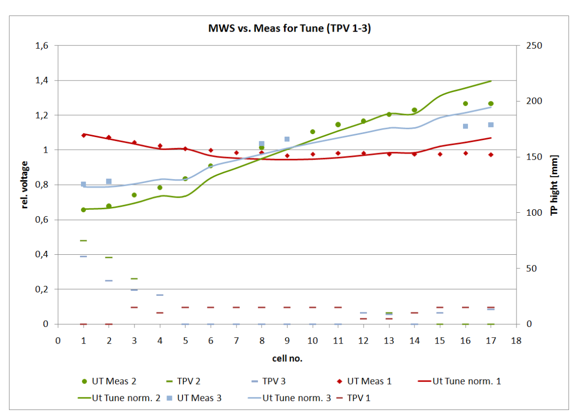

Figure 6: Comparison of Measured Flatness (Dots) for Different Tuning Plate Distributions (Bars) with the Corresponding Results of the Tuning Program (Lines).

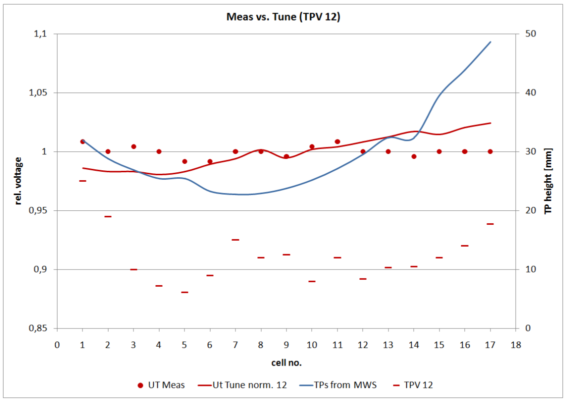

Figure 7: Comparison of the Measurement (Dots) with Results of the Tuning Program (Lines) for the Final Tuning Plate Set Up of the ReA3-RFQ. The Red Distribution is Simulated Based on Measured ECs, While the Blue One Uses Simulated ECs.

INFLUENCE OF PISTON TUNERS

Apart from the tuning plates to tune the longitudinal voltage distribution, piston tuners are used to control the resonance of the RFQ by suppression of the magnetic field [7]. Their influence on the flatness of the RFQ was analysed, focussing on the difference between the upper and the lower electrodes.

Normally either one tuner is positioned in the middle of the resonance structure or two are applied symmetrically. In the case of the ReA3-RFQ two piston tuners are installed in rf cell no. 4 and 14 as shown in the fig. 8. As they are drawn deeper between the stems the voltage drops in that area. The induced defect on the upper (blue) and the lower electrodes (red) is plotted in fig. 9. The maximal change in the flatness is still under 1% even on the lower electrodes. One can see, that the difference between the upper and to lower electrodes is very small, about 0.25%. So that measurement of the upper electrode can be seen as representative for the whole structure.

Figure 8: Piston Tuners in ReA3-RFQ.

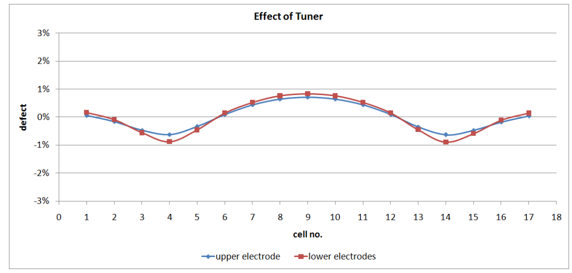

Figure 9: Defect Caused by Piston Tuners.

OUTLOOK

The next steps will be to optimize the calculation of the tuned flatness within the program. A polynomial fit of the effect functions will lead to a more precise simulation of the voltage distribution. A routine will be implemented to find the optimum tuning plate distribution for a constant flatness automatically.

Furthermore measurements on models with different resonance frequencies to check the performance of the tuning program on different RFQs are planed.

With that approach a structured tuning process for the longitudinal voltage distribution will be established which will enable one to predict the tuning plate distribution in the future precisely.

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