

TUNING STUDIES ON 4-ROD RFQs*

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Abstract

A NI LabVIEW based Tuning Software has been developed to structure the tuning process of 4-rod Radio Frequency Quadrupoles (RFQs). Its results are compared to measurement data of 4-rod RFQs in different frequency ranges. For the optimization of 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 especially at higher frequencies. 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. These predictions are based, in contrast to other simulations, on measurements to define the characteristics of the RFQ as it was build - not depending on assumptions of the design. This will lead to a totally new structured process of tuning 4-rod-RFQs in a broad range of frequencies by using the predictions of a software. The results of these studies are presented in this paper.

RESONANT CIRCUITS

A simplified model of the 4-rod RFQ resonator is a chain of LC-oscillators where each RF cell has its own resonance frequency. In these RF cells the stems represent the inductance, while the electrodes form the capacitive part of the circuit. A more detailed model is described in [1].

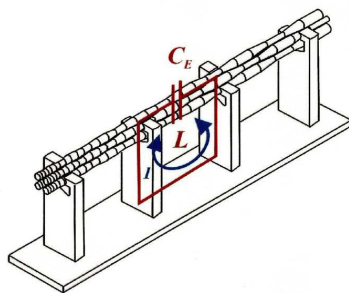


Figure 1: LC Resonator as Equivalent Circuit of a 4-Rod RFQ.

To tune this system, the resonance of each RF cell has to be tuned with tuning plates. They short cut the current path between the stems, to change the inductance of the RF cell. The longitudinal voltage distribution, the so called flatness, is a fundamental parameter in the particle dynamic design of an RFQ. Usually a constant longitudinal voltage along

the electrodes is the basis of our design, but other distributions are possible as well [2]. Following the particle dynamics the longitudinal voltage distribution has to be arranged. It is measured using the capacitive perturbation method. A perturbation capacitor sits on a pair of electrodes of one RF cell to cause a frequency shift due to Thomson's law. The resulting frequency shift of the cell is proportional to its voltage (see Eq. 1).

$$U \propto \Delta f_0 = \frac{1}{\sqrt{LC}} - \frac{1}{\sqrt{L(C + \Delta C)}} \quad (1)$$

THE VOLTAGE TUNING PROCESS

The process of adjusting the flatness is an iterative process of shifting the tuning plates and try to find a set of heights, which results in the desired distribution and total resonance frequency. This process can take some time, especially working on long RFQ structures with a lot of RF cells [3].

Due to several reasons like the changing modulation or differences in the manufacturing, the RFQ has deviations in its characteristics along the electrodes profile [4]. This leads to a different impact of the tuning plates depending on their position in the RFQ.

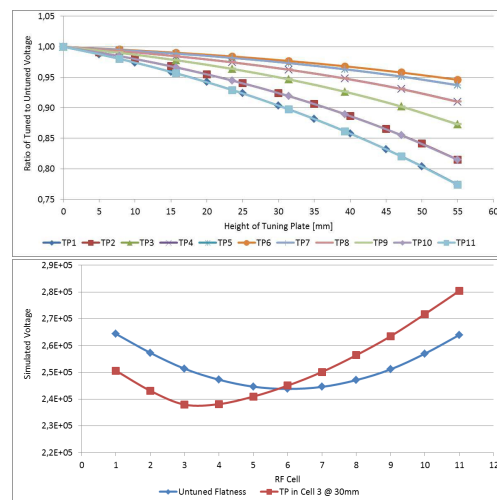


Figure 2: The voltage in $z=k$ from raising tuning plates in all cells (upper graph) and the longitudinal change with a tuning plate in cell $k=3$ (lower graph).

Raising a tuning plate in cell $k \in [1, n]$ decreases the voltage in cell k and its neighboring cells $k \pm i$ with $i < i_0$, while the voltage raises in cells $k \pm i$ with $i \geq i_0$. This behavior is shown in Fig. 2

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In order to quantify this behavior effect functions EC were introduced [5], describing the shift in flatness caused by a change in the position of the tuning plate of each RF cell k. They correspond to the ratio between the tuned and the untuned flatness.

$$U_t(z, h) = U_u(z) + EC(z, h) \times U_U(z) \quad (2)$$

The single tuning plates all have an individual effect on the RFQ $EC_k(z, h)$. Their superposition describes the total effect of a tuning plate setting with different heights h_k .

$$U_t(z, h) = U_u(z) \times \prod_{k=1}^n [EC_k(z, h_k) + 1] \quad (3)$$

To find the ration $EC_k(z, h_k)$ measurements and simulations of the flatness depending on the longitudinal position z in the RFQ and the heights of the tuning plates have been performed with the aim to find a possibility to split $EC(z, h)$ into two separated functions, one for each k depending just on the z-position and one on the height being valid for all k.

$$EC_k(z, h_k) = EC(h_k) \cdot EC_k(z) \quad (4)$$

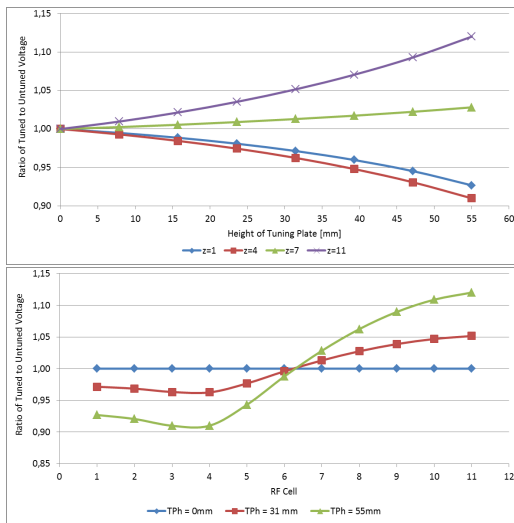


Figure 3: The ratio of the tuned and untuned flatness for a tuning plate in cell k=3 with the height at different z-positions (upper graph) and the corresponding longitudinal change at different heights (lower graph).

STATUS OF THE TUNING PROGRAM

As presented at PAC11 in New York [6] a software has been developed to predict the resulting flatness of an arbitrary tuning plate distribution, which is working well for 4-rod RFQs at 100 MHz. In this version of the program a linear approximation $EC(h)=h$ has been used for the influence of the tuning plates height. Its results in comparison with measurements are presented in Fig. 4

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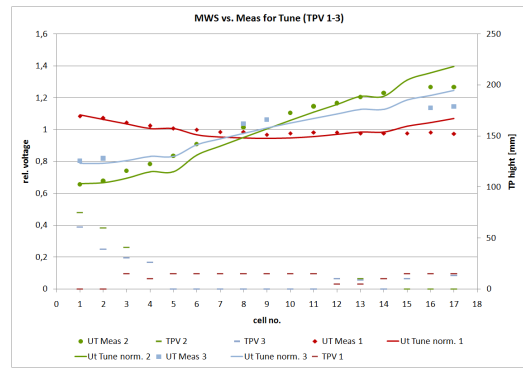


Figure 4: Results of the RFQ tuning program in comparison with three sets of measurements on a 17-cell 100 MHz RFQ [6].

This approximation turns out to be too rough for RFQs with higher frequencies around 200 MHz. Looking at Fig. 3 a square tendency with a - depending on the longitudinal position of measurement z - negative or positive gradient is visible.

To represent this behavior a higher order polynomial fit of the measurement points with different heights was implemented into the software. A comparison of the measured flatness and the simulated predictions with the corresponding tuning plate distribution with a linear and polynomial assumption is shown in Fig. 5.

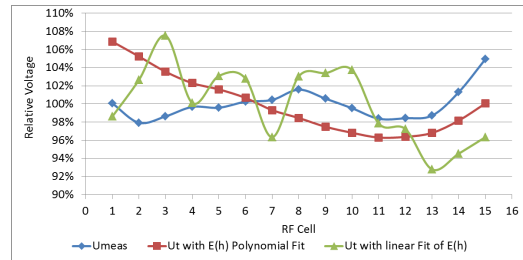


Figure 5: Comparison of the flatness prediction from the RFQ tuning program with linear and polynomial fit in comparison with its corresponding measurement on a 15-cell 200 MHz RFQ.

The measured distribution shows a x^6 -like behavior, which is not included in the simulated ones. Even though the fitted version corresponds to the measurement much better, than the linear approximation, it is unfortunately not in a range to work with.

CONCLUSION AND OUTLOOK

Going from 100 to 200 MHz 4-rod RFQs the dependency of the voltage shift to the height of the tuning plate can not be approximated with a linear function anymore. A polynomial fit has been implemented to the simulation software. The results are much better, but are not precise enough to replace the manual iterative process. Other fitting methods have to be tested. Eventually the splitting of

the longitudinal and height dependency can not be separated as supposed up to now, because their coupling becomes much stronger in high frequency systems. Fig. 6 shows the change in the data sets due to the scaling process for a raising tuning plate in the middle of a 15-cell RFQ. The symmetric increase and decrease of the voltage around the cell of the tuning plate is pictured in the upper graph. This difference disappears with the scaling to h^2 completely. In the scaled case in the lower graph all curves overlap each other and values of the voltage ratios compared to points at higher tuning plate positions gets much smaller.

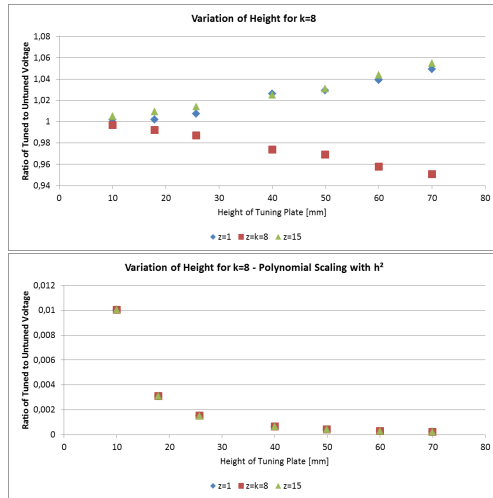


Figure 6: The ratio of the tuned and untuned flatness for a tuning plate in cell $k=8$ - the middle of the RFQ - with the height at different z -positions before the scaling (upper graph) and the corresponding data after applying a scaling with h^2 (lower graph).

Outlook

The vanishing of the differences in the height dependency at varying z -positions will be analyzed further. It may be an indicator of a strong coupling between the height and z -position dependency. If it is not possible to split them, there need to be another method to make the theory of the effect functions useable.

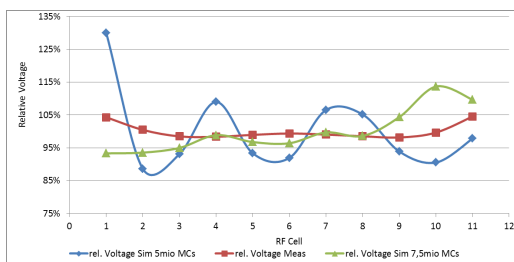


Figure 7: Results of flatness simulations of a 11-cell 200 MHz RFQ with 5 mio. and 7.5 mio. mesh cells in comparison with the corresponding measurement.

In parallel to the development of the simulation software for 4-rod RFQs the simulation of these systems using CST Microwave Studio[®] is about to improve, too. As shown in the graph in Fig.7 there is a strong dependency of the flatness simulation results to the meshing of the RFQ. Both simulation approaches will be followed further, to find a way of predicting the flatness of 4-rod RFQs. At the moment the iterative process is still needed to find the appropriate set up of the tuning plates.

REFERENCES

- [1] J.X. Fang and A. Schempp, "Equivalent Circuit of a 4-ROD-RFQ", EPAC 1992, Berlin, Germany.
- [2] A. Schempp, "Design of Compact RFQs", LINAC 1996, Geneva, Switzerland.
- [3] T. Sieber, "Entwicklung von 4-Rod- und IH- Radio-Frequenz-Quadrupol (RFQ)-Beschleunigern fuer radioaktive Ionenstrahlen bei REX-ISOLDE und MAFF", PhD Thesis, 2001, Munich, Germany.
- [4] J. Schmidt, B. Koubek, A. Schempp "Simulations of the Influence of 4-rod RFQ Elements on its Voltage Distribution", IPAC 2012, New Orleans, LA, USA.
- [5] P. Fischer, "Ein Hochleistungs-RFQ-Beschleuniger fuer Deuteronen", PhD Thesis, 2007, Frankfurt, Germany.
- [6] J. Schmidt, B. Koubek, A. Schempp, "Tuning Studies on 4-rod-RFQs, PAC 2011, New York City, NY, USA.
- [7] A. Schempp, "Overview of Recent RFQ Projects", LINAC 2008, Victoria, BC, Canada.
- [8] P. Fischer and A. Schempp, "Tuning of a 4-rod CW-Mode RFQ Accelerator", EPAC 2006, Edinburgh, Scotland.
- [9] P. Fischer and A. Schempp, "Tuning CW 4-rod RFQ", LINAC 2006, Knoxville, Tennessee, USA.