ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR05

THE LOEWE-3 RFQ PROJECT*

K. Kümpel[1,2,†], S. Altürk[3], H. Höltermann[3], H. Podlech[1,2], U. Ratzinger[1,2,3], J. Storch[1]
[1]Goethe University, Frankfurt am Main, Germany
[2]Hesse for FAIR (HFHF) Campus Riedberg, Frankfurt am Main, Germany
[3]Bevatech GmbH, Frankfurt am Main, Germany

Abstract

The IAP (Institute for Applied Physics) of the Goethe University Frankfurt has a long experience in the development of 4-Rod RFQs. In the course of a project funded by the HessenAgentur as part of LOEWE funding line 3, the basic design of the 4-rod RFQs is now to be further developed. The aim is to investigate whether an improvement in Q-Value and vacuum can be achieved through new production and construction methods, as well as through fundamental adjustments to the basic geometric structure of the 4-Rod RFQ design. The project is divided into two phases. In the first, a simulation model will be created in which all necessary changes that affect the RF properties of the RFQ will be analysed. Based on these results, a demonstrator will then be built on which the innovations can be tested and any improvements analysed. This paper shows the basic ideas of the project as well as the current state of planning.

CURRENT STATUS OF 4-ROD RFQ DESIGN

RFQs (Radio Frequency Quadrupoles) are often used directly after the ion source or LEBT (Low Energy Beam Transport), especially in the low energy range, to accelerate, focus and bunch the ion beam before its further acceleration in subsequent structures. RFQs can be realised both as cavity resonators (e.g. 4-Vane RFQ and IH-RFQ) and as line resonators.

The 4-Rod RFQ is a line resonator whose oscillating structure consists of a series of stems attached to the bottom of the tank, on each of which 2 quadrupole electrodes are alternately attached. Each of the stems can be regarded as a $\lambda/4$ resonator, whereby their height is significantly reduced due to the capacitive termination at the electrodes. In the current design of the 4-Rod RFQ the stems are connected by so-called tuning plates, the height of which can be individually adjusted during assembly of the RFQ. Each pair of neighbouring stems, together with the tuning plate and the electrodes, can be regarded as a separate resonant circuit, which is referred to as an RF cell. The individual resonant circuits of an 4-Rod RFQ are capacitively coupled via the electrodes and inductively coupled via the tuning plates. Figure 1 shows the equivalent resonant circuits of the individual resonant circuits of a current design 4-Rod RFQ with four stems. The vertical position of the tuning plate can be used to change the inductance within an RF cell, which changes the frequency of the cell. The changed frequency of an RF cell causes a local change in the electrode voltage in addition to the global change in the resonant frequency of the entire RFQ. A tuning plate that is moved upwards leads to an increase in the cell frequency and a reduction in the local electrode voltage and vice versa [1].

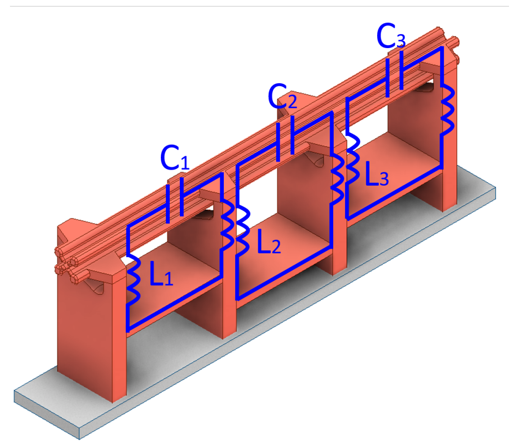

Figure 1: Sketch of a 4-Rod RFQ with the current design with 4 stems in which the equivalent resonant circuits are drawn.

Even though the current design of the 4-Rod RFQ has proven to be very reliable, there are still aspects that can be improved. These include, for example, the Q-factor and vacuum properties.

PLANNED IMPROVEMENT OF THE Q-FACTOR

Usually, the Q-factor measured on a resonator reaches over 90% of the simulated value. With a 4-Rod RFQ, the measured Q-factor is only around 70 - 80% of the simulated one. This discrepancy between the simulation and reality is thought to be caused, among other things, by the contact resistances between the individual components that make up the 4-Rod RFQ. The individual stems, the electrodes and the tuning plates are manufactured separately and fastened together with screws, whereby the connection between stems and tuning plates can also be made using metal springs that are embedded in the tuning plates. As the contact pressure generated by these metal springs is severely limited, the transition between the stems and the tuning plates can also be made using metal springs embedded in the tuning plates.

In order to increase the measurable Q-factor, the LOEWE-3 RFQ project plans to replace the tuning plates used in the current design with tuning blocks that can be screwed to the

---

* Work supported by LOEWE No. HA1575/23-128
† kuempel@iap.uni-frankfurt.de

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR05

stems with a much higher contact pressure than the tuning plates used to date [2]. In this way, the difference between the simulated and measured quality should be measurably reduced.

IMPROVEMENT OF THE VACUUM

In the current 4-Rod RFQ design, rubber O-rings are used to seal the tank. There are 3 O-ring seals per stem installed, one for the stem itself and two more for the accesses to the cooling channels of the electrodes. In addition, the cooling channels of each tuning plate are sealed with two O-rings. As these have significantly poorer properties than metal seals, both in terms of leakage rate and service life, it is planned within the project described here to replace all O-rings with metal seals.

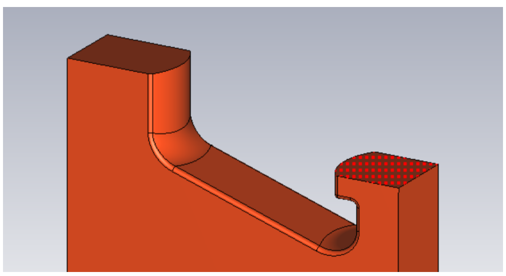

Figure 2: Detailed view of an RFQ stem from above. A "balcony" was added to the mounting surface of the lower electrode (marked in red), which is needed to create enough space for the screws.

By using the tuning blocks mentioned above instead of the previously used tuning plates, the two O-rings previously used here can be replaced by a metal seal that seals the entire tuning block. The stems should also be sealed with precisely this type of seal. This means that the only necessary changes are additional screws, as the metal seals used require a higher contact pressure than O-rings.

As this increased contact pressure is also necessary for the seals of the cooling channels of the electrodes, there must be sufficient space for screws at the transition between the electrode and the stem. As can be seen in Fig. 2, this leads to geometric changes in the resonance structure of the RFQ model where the lower electrode is attached.

The so-called additionally attached "balcony" for fastening the screws displaces the magnetic field and thus reduces the voltage at the lower electrode, which results in a significant increase of up to 18% of the simulated dipole component which made readjustments on the whole simulation model necessary.

THE SIMULATION MODEL

In order to investigate the effects of the planned geometric changes on the RF characteristics of a 4-Rod RFQ, a simulation model was created with the conventional design and adjusted to the desired frequency of 176.1 MHz by varying the height of the tuning plates. This design is used, for example, in the MYRRHA-RFQ [3].

The following Changes were then made to this simulation model:

- replacing the tuning plates with tuning blocks
- inserting the "balcony" on the mounting surface of the lower electrode on the stem (see Fig. 2)
- widening the stems to create enough space for screws and the metal sealing

In addition, the previously used method of dipole compensation, as described in Ref. [4], has been revised. In the previous method, the stems on the side of the lower electrodes were widened in order to increase the voltage at the lower electrode through an extended current path or more space for magnetic fields. In the LOEWE-3 model, the stems were also widened on the side of the upper electrode, but without enlarging the 'cut', the diagonal incision in the stem in which magnetic fields can form, on this side, as shown in Fig. 3. As a result, all stems are aligned on the floor and can be fitted more easily during assembly in the vacuum tank. In addition, the current flow within the individual HF cells is improved, which has a positive effect on the Q-factor.

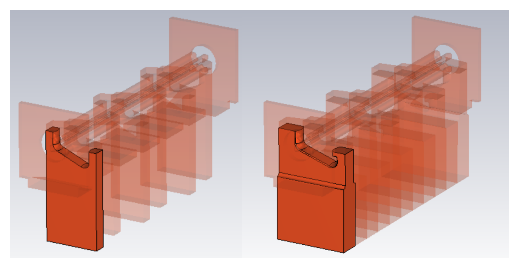

Figure 3: Detailed view of stems of the two compared simulation models. On the left side is the conventional model and on the right side the new LOEWE-3 model. The LOEWE-3 model can be recognized by the widening at the transition to the upper electrode on the stem.

Once the LOEWE-3 simulation model had been created, the desired frequency was also set by varying the height of the tuning blocks. A side view of the two simulation models to be compared is shown in Fig. 4. The two models were then simulated and a selection of important RF parameters can be found in Table 1. The mean value of the upper and lower electrode voltage served as the basis for the specified values of the dipole.

Table 1: Comparison of the simulated values for a 4-Rod RFQ simulation model with 6 stems in the current design (conventional) and in the new LOEWE-3 design for the dipole, the Q-factor and the shunt impedance R_p.

Model	conventional	LOEWE-3
Dipole	2.2%	0.5%
R_p	108 700	113 700
Q-factor	5860	6260

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR05

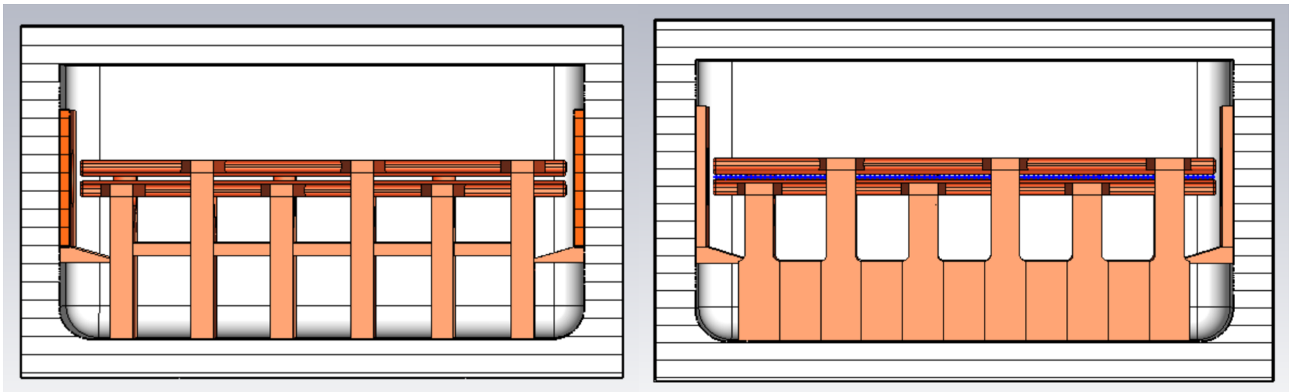

Figure 4: Side view of the two compared simulation models. On the left side is the conventional model and on the right side the new LOEWE-3 model. Clearly recognizable by the widened stems and the tuning blocks that have replaced the tuning plates.

As can be seen in Table 1 the LOEWE-3 model shows both a higher value for R_p and for the Q-factor.

SUMMARY

The LOEWE-3 RFQ project aims to investigate how the previously used 4-Rod RFQ design can be improved in terms of quality and vacuum. The previously used tuning plates are to be replaced by so-called tuning blocks, which can be connected to the stems with a higher contact pressure in order to increase the Q-factor. In addition, the rubber O-ring seals used to date are to be replaced by metal seals in order to significantly improve the vacuum properties. The project is divided into two phases. In the first, which is now nearing completion, a simulation model was created in which all the necessary changes that affect the RF properties of the RFQ were incorporated and simulated. A comparison of the results obtained with the results of a simulation of a conventional RFQ design showed significantly better results in terms of both quality and shunt impedance. The next step is to complete the simulation phase and build and test a demonstrator based on the resulting model.

ACKNOWLEDGEMENTS

This project (HA project no. 1575/23-128) is financed with funds of LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz, Förderlinie 3: KMU-Verbundvorhaben (State Offensive for the Development of Scientific and Economic Excellence).

REFERENCES

[1] K. Kümpel, “Untersuchungen am MYRRHA Injektor”, Ph.D. thesis, Goethe University, Frankfurt, 2022

[2] U. Ratzinger “Linearbeschleuniger, insbesondere Hochfrequenzquadrupol-Beschleuniger, zur Beschleunigung geladener Teilchen, wie beispielsweise Ionen oder Protonen (German Patent No.: DE 10 2021 120 242.6)”, Deutsches Patent- und Markenamt. `https://register.dpma.de/DPMAregister/pat/register?AKZ=1020211202426\&CURSOR=0`

[3] H. Podlech *et al.*, “The MYRRHA-RFQ - Status and First Measurements”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, pp. 2243–2245. `doi:10.18429/JACoW-IPAC2017-TUPVA071`

[4] K. Kümpel *et al.*, “Dipole Compensation of the 176 MHz MYRRHA RFQ”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, pp. 2240–2242. `doi:10.18429/JACoW-IPAC2017-TUPVA070`