ADVANCED DESIGN OPTIMIZATIONS OF A PROTOTYPE FOR A NEWLY REVISED 4-ROD CW RFQ FOR THE HLI AT GSI*

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Abstract

Within the scope of the FAIR project (Facility for Antiproton and Ion Research) at GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, the front end of the existing High Charge State Injector (HLI) is upgraded for cw operation. The dedicated new 4-Rod RFQ structure is currently being designed at the Institute for Applied Physics (IAP) of the Goethe University of Frankfurt. The overall design is based on the RFQ structures that were originally developed for FRANZ and MYRRHA. Regarding the HLI-RFQ the comparatively low operating frequency of 108 MHz causes a general susceptibility towards mechanical vibrations especially concerning the electrodes because of the necessarily larger distance between the stems. Besides RF simulations and basic thermal simulations with CST Studio Suite, the key issues like mechanical electrode oscillations as well as temperature distribution from heat loss in cw operation are investigated with simulations using ANSYS Workbench. At first instance a dedicated 6-stem prototype is currently being manufactured in order to validate the simulated RF performance, thermal behavior and structural mechanical characteristics.

INTRODUCTION

In general 4-Rod Radio Frequency Quadrupole (RFQ) structures for lower operating frequencies are prone to mechanical oscillations because the usually larger distance between the stems facilitates the bending of the inter-stem electrode segments as well as of the levitating electrode extensions. In case of the currently existing HLI-RFQ, which was originally designed within the scope of an intended HLI cw upgrade, the mechanical vibrations cause strong modulated RF power reflections that severely limit the achievable pulse length and amplitude [1]. Measurements of the velocity profile of the electrode vibrations using a laser vibrometer revealed two main types of vibrational modes at approximately 350 Hz and 500 Hz, respectively [2]. Both mode types could later be confirmed and further investigated by structural mechanical eigenmode and resonance response simulations using ANSYS [3]. Thereby the higher modes at 500 Hz could be identified as radial (relating to the beam axis) oscillations of the electrodes that are easily excitable by the radial electric forces associated with the RF pulse. The lower modes at 350 Hz correspond to tangential (relating to the radial axis) oscillations of the electrodes that are excited by asymmetrically acting forces, e.g. originating from the design inherent uneven voltage distribution between the electrodes caused by the intrinsic asymmetries of a 4-Rod RFQ, leading to an electric dipole field component.

In addition to the difficulties with mechanical vibrations the existing structure is also highly sensitive to changes in thermal load which have a significant and nearly immediate effect on the resonance frequency, thus substantially impairing operational stability.

Overall the existing HLI-RFQ which was commissioned at GSI in 2010 [4] fails to fulfill the requirements for the upcoming cw linac. A completely newly revised 4-Rod RFQ is currently being designed with particular attention on structural mechanical stability regarding the susceptibility towards vibrations, especially the severely RF affecting radial electrode eigenmodes, as well as thermal deformations.

RF- AND STRUCTURAL MECHANICAL DESIGN OPTIMIZATIONS

Starting from the basic FRANZ/MYRRHA-RFQ design the crucial geometric parameters were analyzed regarding their influence on the mechanical electrode mode frequencies as well as on the shunt impedance with the aim to yield maximum mechanical rigidity while still obtaining a tolerable overall power loss and moderate local heat loads.

Dipole Compensation

In principle the RF cells of 4-Rod RFQs are capacitively shortened $\lambda/4$-resonators. The voltage distribution on the stems is an almost linear function of the stem height, leading to a higher voltage on the upper electrodes than on the lower ones [5].

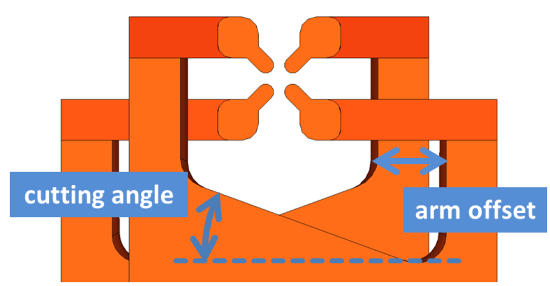

Figure 1: Dipole compensation methods.

One way to compensate the resulting dipole effect is to increase charge transport to the undersupplied electrodes by providing more space for the magnetic field around the stem arms eventually introducing a steeper stem cutting. Another method is to increase the length of the current path to the lower electrodes e.g. by introducing a stem arm offset

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as depicted in Fig. 1. In the end both methods are limited by structural mechanical concerns related to the increased lower stem arm height and width of the trapezoidal electrode mounting segments.

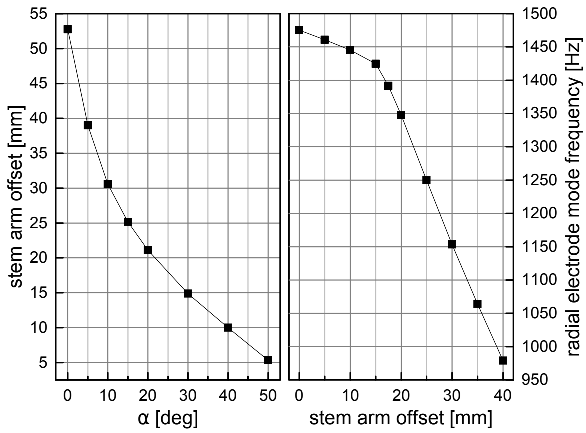

Figure 2: Required stem arm offset for full dipole compensation as function of the stem cutting angle α (*left*) and mechanical radial electrode mode frequency as function of the stem arm offset (*right*).

Considering the required stem arm offset for full dipole compensation in dependence of the stem cutting angle as well as the effect on the mechanical electrode mode frequencies, both shown in Fig. 2, the final prototype design features a stem cutting angle of 30° and a stem arm offset of 15,9 mm.

Electrode Profile & Mounting

Figure 3 depicts the influence of the electrode profile diameter and length of the trapezoidal electrode mountings (see Fig. 4) on the radial electrode mode frequency.

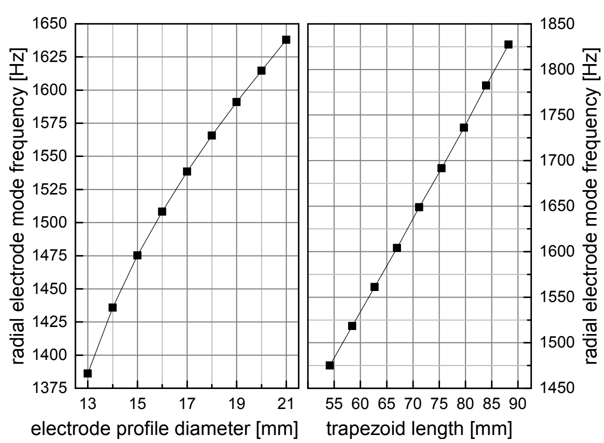

Figure 3: Radial electrode mode frequency as function of the electrode profile diameter (*left*) and base length of the trapezoidal mounting (*right*).

While thicker electrodes result in a higher capacity, thus significantly impairing shunt impedance, the geometry of the electrode mountings has a negligible capacitive influence. Accordingly it is highly beneficial to implement extremely large trapezoid lengths. Eventually the applied electrode diameter is 17 mm and the trapezoid length is 89,2 mm.

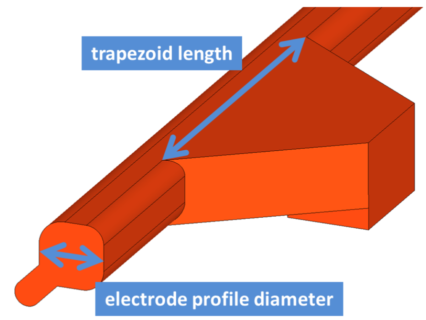

Figure 4: Electrode profile diameter and length of the trapezoidal electrode mountings.

Stem Geometry

The finally reinforced stem geometry is shown in Fig. 5. Both the stem thickness of the 28 cm high stems as well as the width of stem arms were increased in order to prevent mechanical vibration modes and increase the overall rigidity.

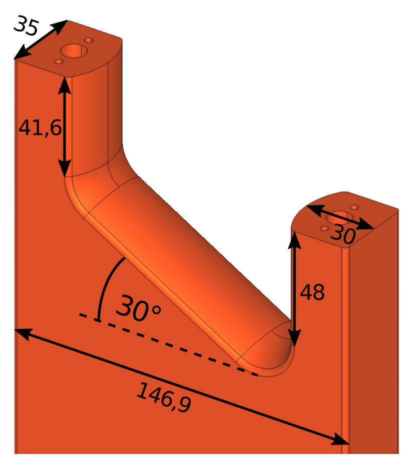

Figure 5: Reinforced stem geometry.

FINAL PROTOTYPE DESIGN

Originating from a previously intended 4-stem design the final prototype configuration was upgraded to 6 stems in order to reproduce a mechanical resonance mode spectrum of the electrodes that is comparable to a longer structure.

For the purpose of vibrometer measurements the RFQ tank is fitted with four windows in total (CF 63). Two of them are located on the upper cavity cap (slightly visible in Fig. 6) with one targeting the upper electrode extension and the other targeting the inter-stem electrode segment adjacent to the opposite electrode end. The other two windows are fitted sideways with each again being targeted to one of the same respective spots, thus enabling the measurement of vibration velocity profiles on two designated points in two spatial directions.

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For the validation of the simulated temperature distribution each stem will be fitted with a drilled channel that is accessible from below for mounting temperature sensors close to the thermally loaded stem surface.

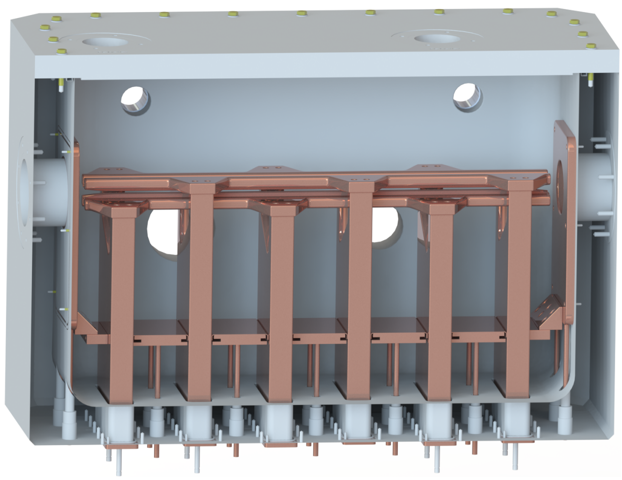

Figure 6: Final 6-stem prototype design.

The simulated RF properties and basic parameters of the final 6-stem prototype design are shown in Table 1. The stated value for the shunt impedance is scaled down with a factor of 0,75 from the original CST MWS simulation result. Considering the final full-size HLI-RFQ with an electrode length of ≈2 m the expected power dissipation of 31,3 kW/m at a reference electrode voltage of 60 kV would allow operation using a 100 kW power amplifier

Table 1: Simulated RF Properties and Basic Design Parameters of the 6-stem RFQ Prototype

RF frequency [MHz]	108
shunt impedance [kΩ·m]	115
electric dipole ratio [%]	≈ 0
power loss [kW/m]	31,3
reference electrode voltage [kV]	60
tuning range (tuning plates) [MHz]	± 15
dynamic tuning range (plunger tuner) [kHz]	± 200
electrode length [mm]	702
aperture radius [mm]	4
electrode radius [mm]	3
stem distance [mm]	120
stem height [mm]	282,7

SUMMARY & OUTLOOK

Based on the original FRANZ/MYRRHA-RFQ design (175/176,1 MHz) a 6-stem prototype for a completely newly revised HLI-RFQ (108 MHz) was developed. By optimizing the stem distance, electrode profile and length of the trapezoidal electrode mountings the resonance frequencies of the RF affecting mechanical electrode modes could be increased by a factor of approximately 4 compared to the existing HLI-RFQ (see Fig. 7), thus significantly enhancing mechanical rigidity. In order to structurally compensate the comparatively large stem height of roughly 28 cm also the stem geometry was optimized and reinforced. By varying the stem cutting angle and introducing a stem arm offset the electric dipole component could be compensated entirely.

The prototype structure is currently under construction at Neue Technologien GmbH, Gelnhausen, Germany. The completion of construction is expected until spring 2017.

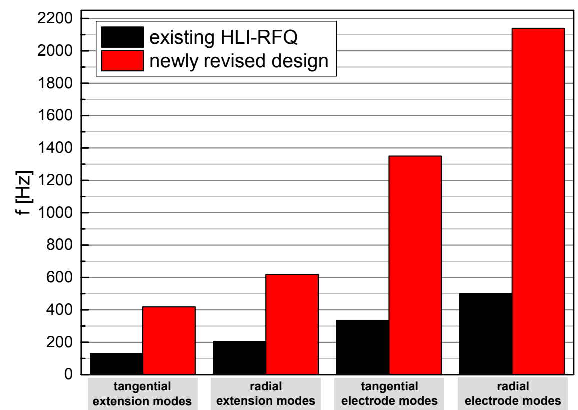

Figure 7: Mechanical electrode resonance frequencies of the existing HLI-RFQ and the newly revised design

ACKNOWLEDGEMENT

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