PROTOTYPE DESIGN OF A NEWLY REVISED CW RFQ FOR THE HIGH CHARGE STATE INJECTOR 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 planned to be upgraded for cw operation. The required newly revised 4-Rod RFQ structure is currently being designed at the Institute for Applied Physics (IAP) of the Goethe University of Frankfurt. It will be operated with a 100 kW power amplifier at 108 MHz. At first instance a dedicated 4-stem prototype, which is based on the RFQ design for MYRRHA [1] and FRANZ [2], is planned to be manufactured in order to validate the simulated RF performance, thermal behavior and mechanical characteristics in continuous operation. The RF simulations as well as basic thermal simulations are done using CST Studio Suite [3]. In order to prevent oscillations of the electrodes mechanical eigenmodes are analyzed using ANSYS Workbench [4]. In addition the ANSYS Multiphysics software allows more sophisticated simulations regarding the cooling capability by considering fluid dynamics in water cooling channels, thus providing a more detailed thermal analysis.

INTRODUCTION

An already existing 4-Rod Radio Frequency Quadrupole (RFQ) which was originally designed for cw operation in the HLI was commissioned in 2010 at GSI [5]. Unfortunately the structure suffers from strong modulated RF power reflections with a frequency of approximately 500 Hz that severely limit the achievable pulse length and amplitude [6]. Measurements of the velocity profile of the electrodes using a laser vibrometer identified vibrations as source of the RF modulations as well as the edges of the RF pulse as their excitation [7]. Additionally other vibrational modes around 350 Hz were found that however do not affect the RF behavior. In general 4-Rod 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 existing HLI-RFQ the structural instability is also supported by the use of a thin electrode profile that was originally implemented in order to keep down the overall capacitance thus reducing power loss. Besides the difficulties with mechanical vibrations the structure is also highly sensitive to changes in thermal load which have a significant and nearly immediate effect on the resonance frequency [6]. After all the operation of the existing RFQ is still restricted and complicated. Since the requirements for the upcoming cw linac are not fulfilled a newly redesigned RFQ is highly desirable.

Based on the acquired experiences it becomes apparent that besides RF optimization also a comprehensive structural mechanical and thermal analysis has to be considered for the overall design in order to ensure general operationality as well as to fulfill the requirements of cw operation.

ELECTRODE EIGENMODES

Using the modal analysis solver of ANSYS Workbench the mechanical eigenmodes of a single electrode rod of the existing HLI-RFQ were determined.

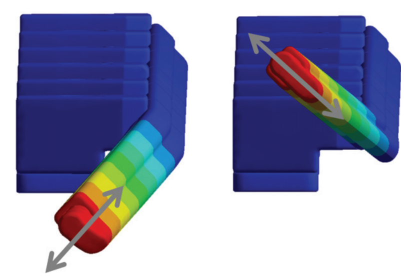

Figure 1: tangential (relative to the beam axis, *left*) and radial (*right*) eigenmodes of the electrode extension.

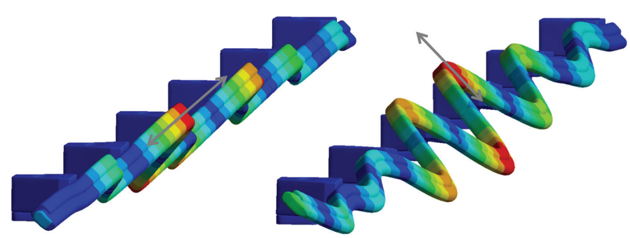

Figure 2: tangential (relative to the beam axis, *left*) and radial (*right*) eigenmodes of the entire electrode rod.

The yielded eigenmode spectrum (Fig. 4) shows properties that are typical for any 4-Rod RFQ structure:

The two lowest eigenmodes correspond to vibrations of the electrode extension (*extension modes*) as depicted in Fig. 1. Since the rod has in a simplified view a rectangular profile with two symmetry planes there occur tangential and radial modes relative to the beam axis. Analogously the eigenmodes associated with oscillations of the inter-stem segments of the electrode as shown in Fig. 2 (*electrode modes*) can be classified.

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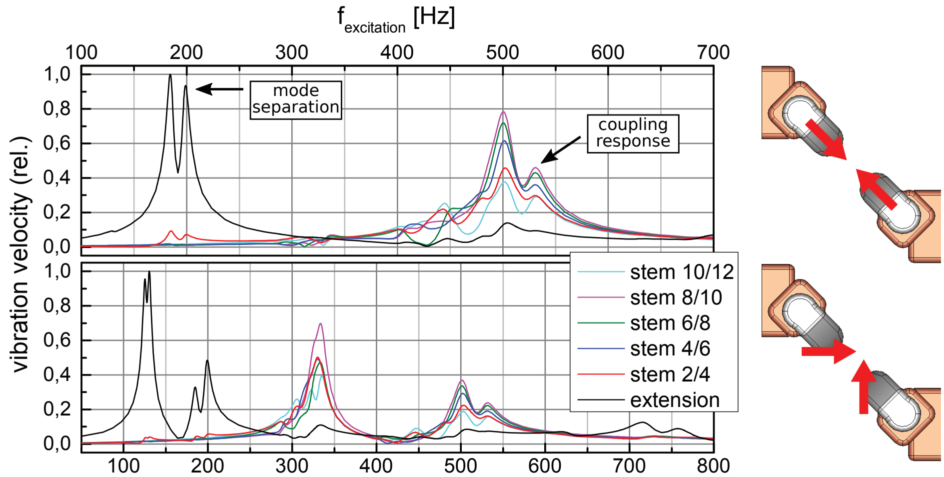

Figure 3: simulated resonance response spectra regarding monitoring points between different stem pairs on the upper electrode of the existing HLI-RFQ for excitations in diagonal (*top*) as well as horizontal/vertical (*bottom*) direction.

The range of the simulated tangential electrode modes (329 - 340 Hz) roughly matches the 350 Hz oscillations from the vibrometer measurements and the range of the radial electrode modes (497 - 539 Hz) suit the 500 Hz vibrations which is also the modulation frequency of the observed RF power reflections. Thus it can be concluded that in general radial modes, particularly the lowest ones, have the most significant influence on the overall capacitance and as a consequence cause problems regarding RF matching.

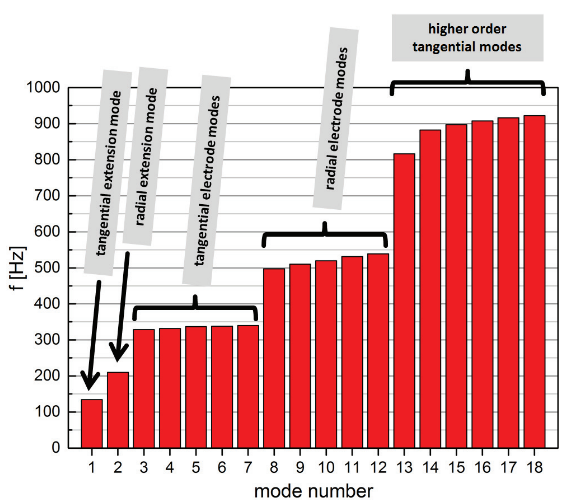

Figure 4: simulated spectrum of mechanical eigenmodes of the existing HLI-RFQ for $0 \leq f \leq 1$ kHz (single upper electrode).

By doing a harmonic analysis the resonance response can be determined for a set of monitoring points on the structure surface and a predefined excitation (force and direction). Fig. 3 shows the simulated resonance response spectra for different excitation scenarios. Diagonal excitation suppresses all tangential modes whereas the response spectrum for horizontal/vertical excitation contains one peak for each class of eigenmodes. These simulations were done for a pair of electrodes including the stems on which they are mounted. Since the covibration modes of the stem arms have a slight influence on the eigenmode frequencies of the electrode extensions there occurs mode separation and the originally sharp peaks of the spectrum split up. Regarding the resonance response of the radial electrode modes (around 500 Hz) another smaller peak occurs which originates from the coupling to the resonance of the opposite electrode via the stem.

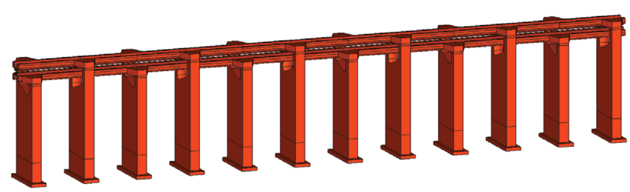

Figure 5: 12-stem model of the FRANZ/MYRRHA RFQ design for structural mechanics simulations (without tuning plates).

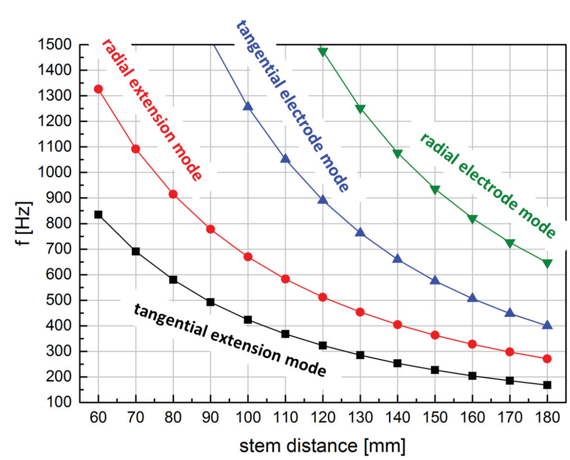

Figure 6: eigenmode frequencies as function of the stem distance for the 12-stem model as depicted in Fig. 5.

The eigenmode frequencies depend mostly on the electrode profile and on the stem distance. Fig. 6 depicts the

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influence of the stem distance on the eigenmode frequencies of a 12-stem RFQ model as shown in Fig. 5. At the reference stem distance of 173 mm of the existing HLI-RFQ the thicker electrode profile of the MYRRHA/FRANZ RFQ design increases the frequency of the critical radial electrode mode to roughly 700 Hz. Higher frequencies are attributed to higher mechanical rigidity and smaller oscillation amplitudes.

RF OPTIMIZATION

The simulations for RF optimization are done on a 4-stem model as depicted in Fig. 7 from which later on a prototype is planned to be manufactured in order to validate the simulations. Overall the FRANZ/MYRRHA RFQ design (175/176,1 MHz) provides good RF performance at the lower operating frequency of 108 MHz of the HLI. At 55 kV intervane voltage and a shunt impedance of 125 kΩ·m, corresponding to the maximum of the shunt impedance curve plotted in Fig. 8, the power dissipation is roughly 24 kW/m which is well below the values that have been already approved for safe operation.

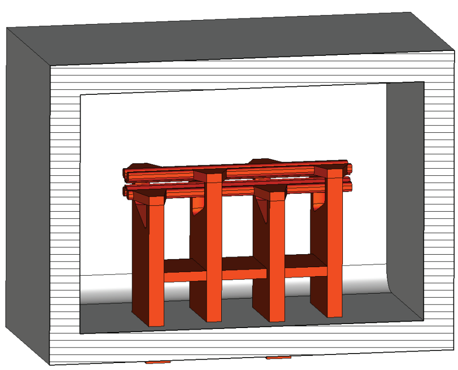

Figure 7: CST model of the 4-stem prototype.

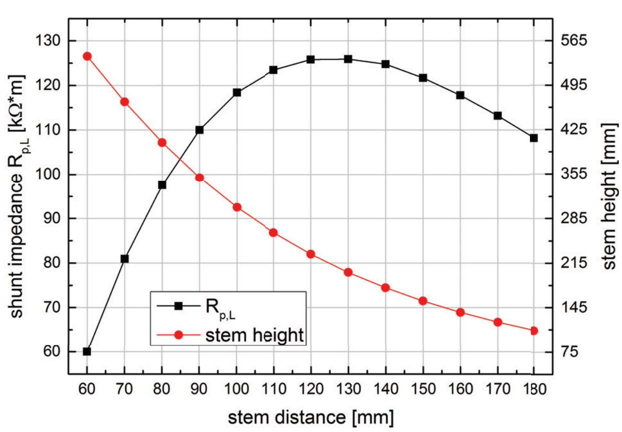

Figure 8: shunt impedance and stem height of the 4-stem prototype as function of the stem distance.

The electric dipole which is due to the low operating frequency typically at a comparatively low ratio around 10 % can either fully or partially be compensated by the stem cutting or by introducing a sideways offset to the lower stem arms thus increasing the current path to the lower electrodes.

CONCLUSION & OUTLOOK

The structural mechanical simulations allowed to identify the RF affecting eigenmodes of the existing HLI-RFQ which regarding a completely redesigned structure can be effectively suppressed with a thicker electrode profile and a reduced stem distance. Previous measurements from GSI allowed to benchmark and validate the simulations. The RF simulations showed that the FRANZ/MYRRHA RFQ design is perfectly applicable for the HLI operating frequency of 108 MHz regarding shunt impedance, power loss per meter, dipole ratio and tuning range. In order to compensate for the higher overall capacitance an upgrade of the power amplifier to 100 kW is planned.

In order to investigate thermal effects in cw operation basic simulations with CST MPhysics Studio will be done soon. In addition more sophisticated simulations with ANSYS Multiphysics are planned taking into account fluid dynamics in cooling channels as well as heating of the cooling water. The simulations for the optimization and the determination of the final parameters for the 4-stem prototype should be done by the middle of the year, enabling the subsequent beginning of manufacturing.

ACKNOWLEDGEMENT

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