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INITIAL MEASUREMENTS ON A NEW 108 MHZ 4-ROD CW RFQ PROTOTYPE FOR THE HLI AT GSI*

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Abstract

The High Charge State Injector (HLI) at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, is one of the two injector linacs for the Universal Linear Accelerator (UNILAC) and is also planned to serve as dedicated injector for a proposed superconducting CW linac for heavy element research [1]. Within the scope of an intended CW upgrade of the HLI front end [2], a replacement for the existing 4-rod RFQ is desirable since its stable operation and performance is severely impeded by mechanical vibrations of the electrodes and a high thermal sensitivity [3]. With the aim of suppressing mechanical vibrations and providing efficient cooling considering high power CW operation, a completely new and improved 4-rod design was developed with a focus on structural mechanical simulations using ANSYS [4, 5]. In order to validate the simulated RF performance, thermal behavior and structural mechanical characteristics, a 6-stem prototype was manufactured. Initial low power RF measurements and basic piezo-"-actuated mechanical investigations were done and the anticipated properties could be confirmed prior to planned high power RF tests and further mechanical vibration studies.

INTRODUCTION

The existing HLI-RFQ, which was commissioned in 2010, suffers from mechanical vibrations of the electrodes that are excited by the edges of the RF pulses [3]. This causes severe modulated RF power reflections that limit the achievable performance and impede stable operation. The critical vibrational modes of the structure were identified by vibration measurements with a laser vibrometer and from a structural mechanical analysis using ANSYS [6]. This showed that in particular radial modes, oscillating perpendicular to the beam axis, are easily excited by the electric forces of the quadrupole field configuration and lead to significant fluctuations of the overall capacitance. In addition to the structural susceptibility towards mechanical vibrations, the existing HLI-RFQ is also highly sensitive to changes in thermal load, which in conjunction with the vibration problem makes it also difficult to reach stable CW operation.

In order to overcome both problems, a completely newly revised 4-rod RFQ design for an RF frequency of 108 MHz was developed at IAP [4, 5], based on the already proven design concepts of the RFQs for FRANZ and MYRRHA. In order to validate the simulated mechanical and RF characteristics, a 6-stem prototype was manufactured by NTG [7] (see Fig. 1 and Fig. 2) and delivered to IAP in November 2017. Prior to conditioning and planned high power tests, initial RF and mechanical measurements were done. The results are in good agreement with both the simulated RF parameters and the anticipated mechanical behavior.

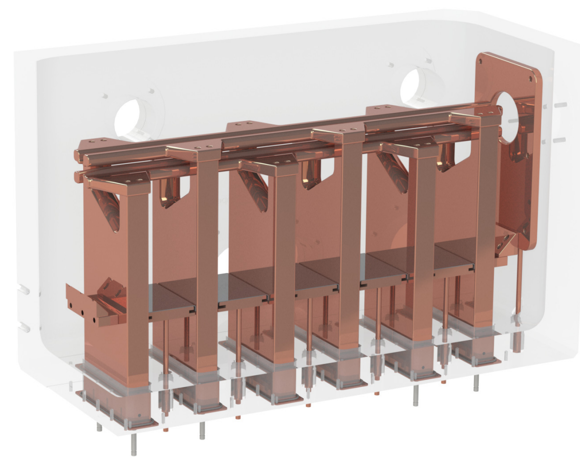

Figure 1: Rendered sectional view of the 6-stem prototype with transparent tank.

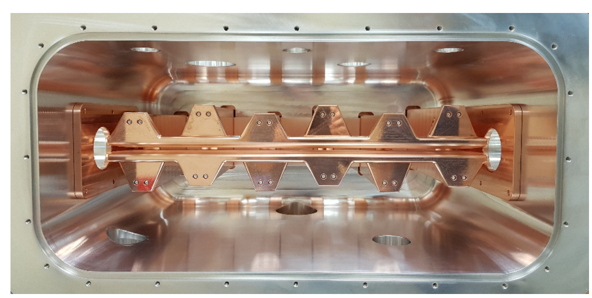

Figure 2: Topview of the 6-stem prototype (photo taken by NTG [7]).

RF MEASUREMENTS

The RF measurements were done with a network analyzer and a provisional coupling loop at the open tank. For frequency and flatness tuning five dummy tuning plates were used and no dynamic plunger tuner was mounted. The RF resonance frequency was measured for different positions of the tuning plates, being the distance from the tank bottom to the upper side of the plates while all five plates were kept at the same height at all times. The measured values differ insignificantly little (due to the open tank and the absence of a plunger tuner) from the simulations for the entire design

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frequency range from 93 MHz to 123 MHz, corresponding to 108 ± 15 MHz. For the measurement of the voltage distribution and dipole ratio a 1 pF perturbation capacitor was used, which can be attached between two electrodes with a mounting bracket as depicted in Fig. 3.

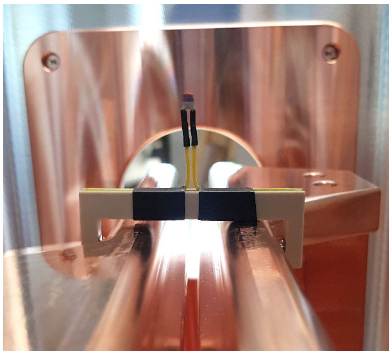

Figure 3: Perturbation capacitor (1 pF) on PEEK mounting bracket.

The dipole ratio is calculated according to Eq. 1 [8] with U_u and U_d being the voltages between the upper and lower electrode pairs, respectively, and Δf_u and Δf_d being the corresponding frequency shifts due to the perturbation capacitance. The voltage deviation (Eq. 2) is calculated from the frequency shift Δf in the respective RF cell and $\Delta f_\mathrm{reference}$ in a reference cell.

$$\text{dipole ratio} = \frac{U_\mathrm{u} - U_\mathrm{d}}{U_\mathrm{u}} = \frac{\sqrt{\Delta f_\mathrm{u}} - \sqrt{\Delta f_\mathrm{d}}}{\sqrt{\Delta f_\mathrm{u}}} \tag{1}$$

$$\text{voltage deviation} = 1 - \sqrt{\frac{\Delta f}{\Delta f_\mathrm{reference}}} \tag{2}$$

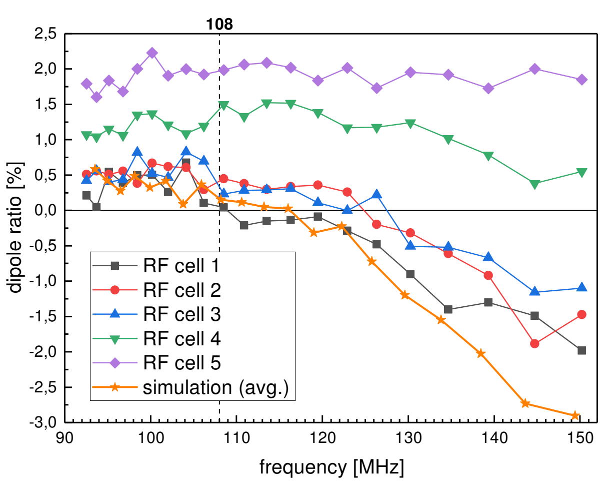

Figure 4: Measured dipole ratio in different RF cells as function of the frequency and comparison with simulation.

As shown in Fig. 4, for the first three RF cells the measurements match the simulated values nicely, whereas for cells 4 & 5 this is not the case. Overall the dipole ratio is very low (< 0,5 %) across the entire design frequency range and the overcompensation increases only insignificantly for much higher frequencies up to 150 MHz. The voltage distribution along the upper electrodes (flatness) is depicted in Fig. 5 and shows an unexpected tilt for cells 4 & 5. These deviations are probably due to a mechanical misalignment of the electrodes that can even be visually recognized on closer inspection.

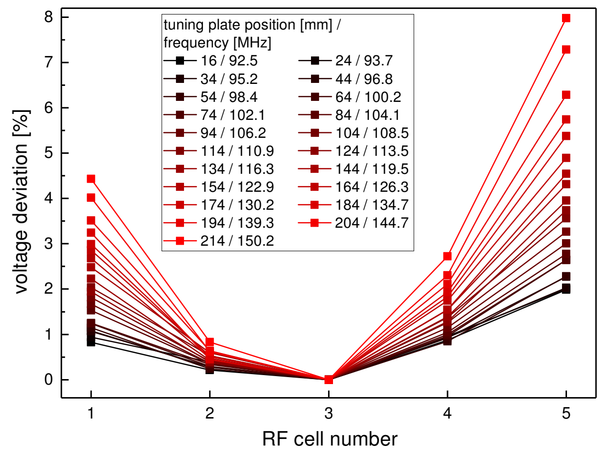

Figure 5: Measured voltage distribution along the upper electrodes (flatness) for different tuning plate positions (all at same height) / frequencies.

The measurements of the quality factor Q with weak and critical coupling yielded a value of 4000, which is 60 % of the simulated (6700) and 80 % of the expected value (5000, 75 % of the simulation).

MECHANICAL MEASUREMENTS

First mechanical investigations were done with a piezo-actor/sensor system, which was mounted through the ISO-F 63 diagnostic flanges as depicted in Fig. 6. The frequency spectra of the resonance response were calculated by applying fast Fourier transform to the sensor signal. Because the mechanical eigen oscillations especially of the piezo-actor mounting structure itself severely derange the measured spectra, dismounting the piezo-actor and introducing the excitation by tapping the structure with a rubber-tipped hammer instead yields much more accurate and comprehensible response spectra.

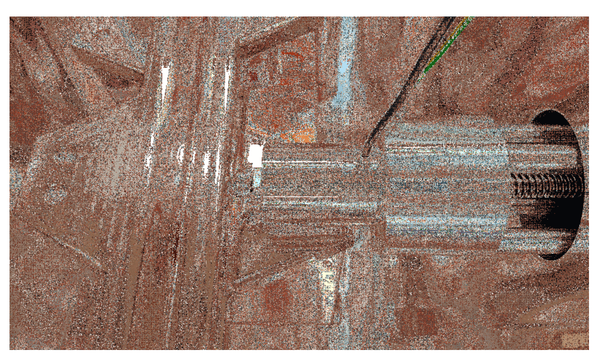

Figure 6: Piezo-sensor on inter-stem electrode segment mounted through an ISO-F 63 flange.

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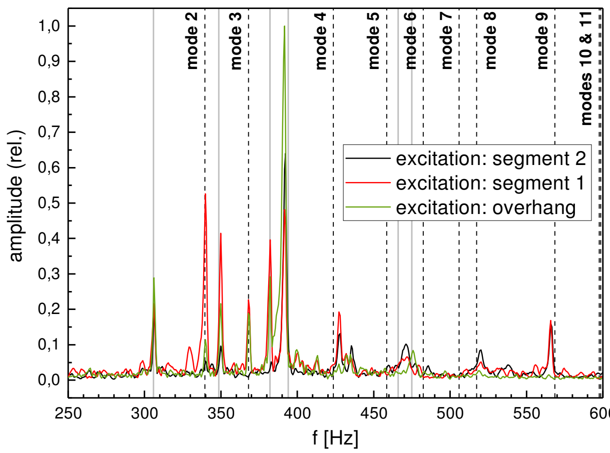

Figure 7: Measured frequency spectra of the electrode vibration amplitude for differently located excitations and comparison with simulated modes (black dashed lines) and measured resonances of the piezo mounting structure (gray lines, see Fig. 8).

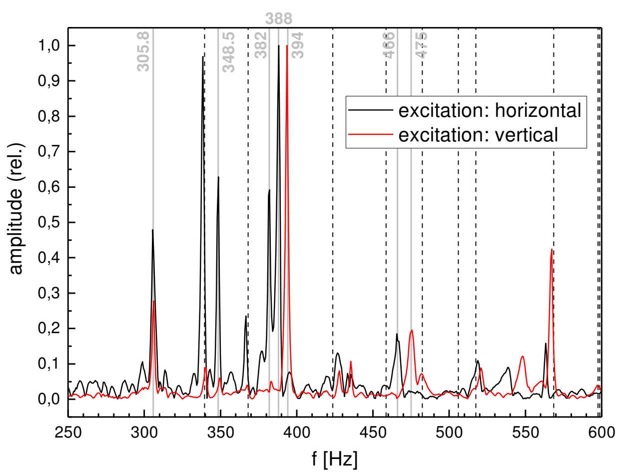

Figure 8: Measured frequency spectra for the vibration of the piezo mounting structure for horizontal and vertical excitation with the piezo pressed against the electrode.

The resonance response spectra at an inter-stem electrode segment for different excitations are shown in Fig. 7 and contain besides modes of the actual RFQ structure, as expected from the ANSYS simulations, several other response peaks. By comparison with the yielded spectra for excitations directly applied to the piezo mounting structure (see Fig. 8), these modes can mostly be identified as eigen oscillations of the mounting structure itself. Under exclusion of the presumable mounting structure modes, the experimentally obtained mode spectrum is in fairly good agreement with the structural mechanical simulations.

A major improvement over the piezo-based response measurement technique would be the use of a non-contacting sensor, e.g. like a laser vibrometer, that does not mechanically interfere with the investigated structure.

SUMMARY & OUTLOOK

A 6-stem prototype of a newly revised 4-rod CW RFQ design was manufactured and is currently being investigated at IAP. In initial measurements the from preceding simulations anticipated most important RF and structural mechanical properties could be validated. Only the value of the measured quality factor is roughly 20 % lower than expected, which requires further investigations. Nevertheless the original design requirement for a power consumption of less than 35 kW/m still seems achievable. A more precise alignment of the electrodes with ensuing new low power RF measurements seems desirable as well as the use of a laser vibrometer for more sophisticated structural mechanical investigations. Conditioning and high power tests of the prototype are currently in preparation.

ACKNOWLEDGEMENTS

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REFERENCES

[1] W. Barth, K. Aulenbacher, M. Basten, F. Dziuba, V. Gettmann, M. Miski-Oglu, H. Podlech, S. Yaramyshev, "A Superconducting CW-LINAC for Heavy Ion Acceleration at GSI", EPJ Web of Conferences **138**, 01026 (2017).

[2] P. Gerhard, L. Groening, W. Hartmann, S. Mickat, K. Tinschert, H. Vormann, K.-O. Voss, "Status and Perspectives of the CW Upgrade of the UNILAC HLI at GSI", in *Proc. HIAT'15*, Yokohama, Japan, paper WEA1C03, p. 183-185 (2015).

[3] P. Gerhard, L. Groening, K.-O. Voss, "In Situ Measurement of Mechanical Vibrations of a 4-Rod RFQ at GSI", in *Proc. LINAC'14*, Geneva, Switzerland, paper TUPP057, p. 553-555 (2014).

[4] D. Koser, P. Gerhard, L. Groening, O. Kester, H. Podlech, "Prototype Design of a Newly Revised CW RFQ for the High Charge State Injector at GSI", in *Proc. IPAC'16*, Busan, Korea, paper MOPOY020, p. 889-891 (2016).

[5] D. Koser, P. Gerhard, L. Groening, O. Kester, H. Podlech, "Advanced Design Optimizations of a Prototype for a Newly Revised 4-Rod CW RFQ for the HLI at GSI", in *Proc. LINAC'16*, East Lansing, MI USA, paper TUPLR057, p. 586-588 (2016).

[6] D. Koser, P. Gerhard, L. Groening, O. Kester, H. Podlech, "Structural Mechanical Analysis of 4-Rod RFQ Structures in View of a Newly Revised CW RFQ for the HLI at GSI", in *Proc. IPAC'17*, Copenhagen, Denmark, paper THPIK021, p. 4142-4144 (2017).

[7] Neue Technologien GmbH & Co. KG (www.ntg.de/en)

[8] K. Kümpel, A. Bechtold, C. Lenz, N.F. Petry, H. Podlech, C. Zhang, "Dipole Compensation of the 176 MHz MYRRHA RFQ", in *Proc. IPAC'17*, Copenhagen, Denmark, paper TUPVA070, p. 2240-2242 (2017).