HIGH POWER TESTS OF A NEW 4-ROD RFQ WITH FOCUS ON MECHANICAL VIBRATIONS

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Abstract

Because of strong mechanical vibrations of the electrodes and its sensitivity to changes of thermal load, the operational stability of the existing 4-rod RFQ at the High Charge State Injector (HLI) at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, could not be ensured for all planned operating states. To resolve this issue and ensure stable injection into the HLI, a new RFQ-prototype, optimized in terms of vibration suppression and cooling efficiency, was designed at the Institute of Applied Physics (IAP) of Goethe University Frankfurt. To test the performance of this prototype and demonstrate the operational stability in terms of mechanical vibration as well as thermal load, high power tests with more than 25 kW/m were performed at GSI. After initial conditioning, detailed vibrational measurements during high power RF operation using a laser Doppler vibrometer were performed, which were then compared to previously conducted simulations using ANSYS. Ultimately, the ability for stable operation up to high power levels with an efficient vibration suppression and moderate heating have clearly been demonstrated.

INTRODUCTION

To meet the increasing requirements in terms of beam quality and RF duty cycle for the planned HLI upgrade program, a new 4-rod RFQ has been commissioned and integrated into the High Charge State Injector (HLI) at GSI in 2010 [1]. To achieve the HLI operating frequency of 108 MHz and reduce the RF power dissipation to less than 60 kW, as provided by the designated power amplifier at that time, this RFQ design features a large stem distance of 173 mm as well as a thin profile of the RFQ electrode rods to reduce capacitance. These structural properties favor increased mechanical vibrations of the electrodes; especially at the levitating electrode overhangs and the inter-stem sections [2]. The electrode vibrations periodically alter the overall capacitance of the RF structure, resulting in an impedance mismatch, which leads to modulated power reflections. This poses significant problems for the tuning of the RF frequency by the plunger tuner [3]. To identify the problematic vibration modes of the existing HLI-RFQ, comprehensive structural-mechanical simulations as well as vibration measurements using a laser Doppler vibrometer were conducted. Based on this analysis a newly revised 4-rod RFQ prototype with 6 stems was designed and tested at high average power levels (>25 kW/m) at GSI. Here we present the mechanical vibration measurements during high power operation together with a comparison to simulations using CST Studio Suite [4] and ANSYS [5].

MODAL ANALYSIS

One of the defining properties of mechanical oscillation is the eigenfrequency of the observed mode. If the frequency of the mode corresponds to a multiple of the frequency of excitation, amplified harmonics can arise.

Numerical Simulations

With specialized simulation software, like the ANSYS-program package, it is possible to simulate the behavior of a rigid body under the influence of an applied force. For the here presented results, two different methods of simulation have been performed. First, a harmonic simulation, in which a harmonic load is applied, and second a transient simulation in which it is possible to define force-pulses and analyze the response of the object [6]. Even though the harmonic simulation does not yield good quantitative results for the performed experiment, it is a good method to determine the dominant modes of the structure, which are shown in Fig. 1.

To make assumptions regarding the amplitudes of existing oscillations, a much more time-consuming transient simulation is needed. Here it is possible to define the duration, orientation, and amount of an applied force. Using the square relation between the Lorentz force acting on the electrodes (F_L) and the power inside the cavity (P_C) it is possible to tune the simulated force to a corresponding one which existed during experimental measurements.

The simulated velocity and displacement of an inter-stem section is presented in Fig. 2. The strong visible displacement to negative magnitudes is due to restrictions in implementing the force: In reality, due to the very high frequency utilized in the cavity, the electric field would quickly oscillate for every position on the electrode. The corresponding force would therefore change between its maximal value and zero approximately every 10 ns. This is nearly impossible to implement into the software. The way the force was implemented is as a constant applied force with a pulse duration of 6.5 ms, which is applied evenly to the whole electrode and therefore resulting in a stable position in negative displacements, around which the electrode oscillates. The simulated results regarding vibration velocity and displacement are shown in Fig. 2.

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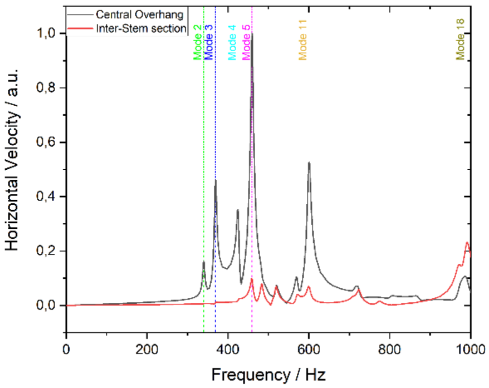


Figure 1: Simulated horizontal velocities in dependence of the frequency.

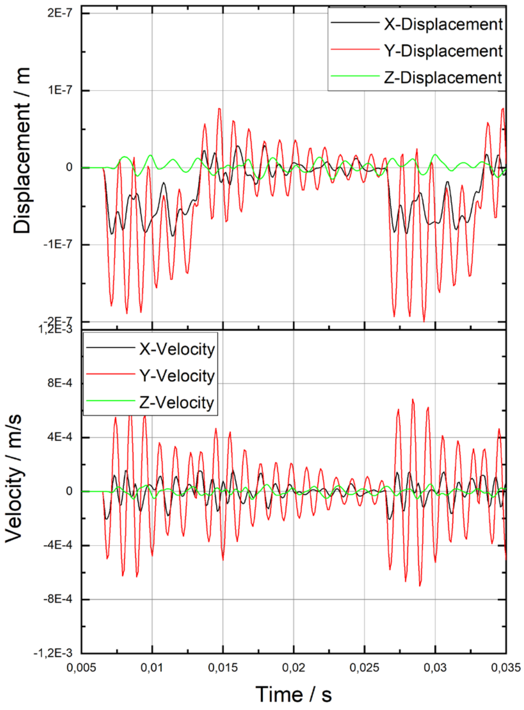


Figure 2: Simulated results for an inter-stem section of the electrode with a force corresponding to 22 kW/m.

Experimental Examination

Before RF-conditioning started, an intense modal analysis has been performed using a 3-D-Laser-Vibrometer. For this measurement, the electrodes were stimulated in various means, as is described in [2].

During high power tests at the GSI, it was possible to conduct vibrometer measurements with active RF-power. The setup for such measurements is depicted in Fig. 3. Due to the lack of space in the bunker, it was only possible to use one scan head of the vibrometer, turning the possible three-dimensional observation into a one dimensional one. Even though that was the case, the results match the expectations very well. The horizontal velocity in dependence of the frequency is shown in Fig. 4.

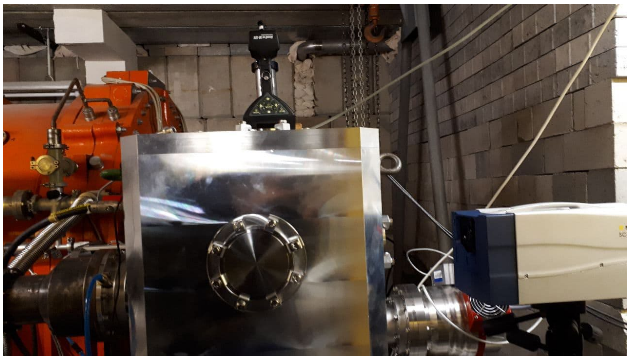


Figure 3: RFQ with Laser-vibrometer.

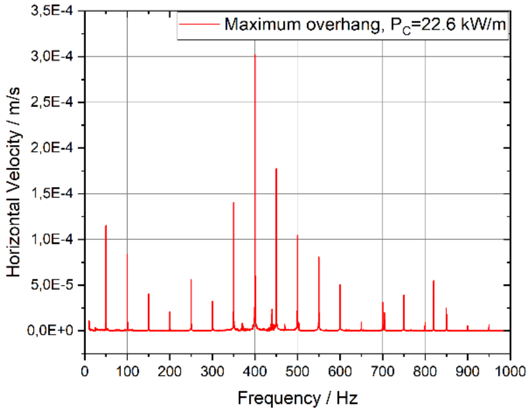
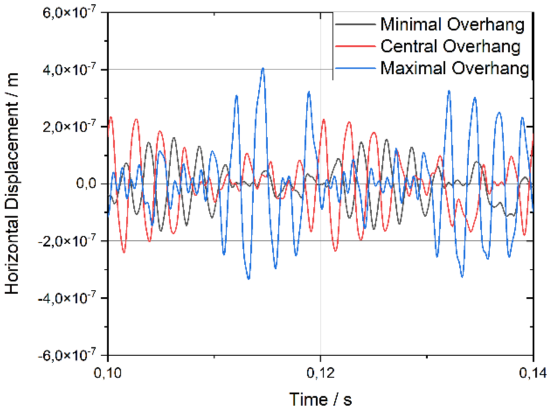


Figure 4: Measured horizontal velocity for the maximum overhang.

The resulting velocity and displacement, that a structure experiences, depends largely on their position. While the overhang experiences the strongest measured velocities of up to 1 mm/s were the velocities and the pulse structure for the inter-stem section hardly visible. Here, the maximum obtained values were in the range of 0.5 mm/s for a much higher power value.

COMPARISON WITH SIMULATIONS

In addition to the measurement of the excitation in dependence of the frequency, absolute values for the velocity were obtained. The measured velocities of three different parts of the overhang as well as the with them calculated displacement is depicted in Fig. 5. It is clearly visible, that the absolute values for velocity and displacement increase the father away from the stem the measuring point is. In addition to different amplitudes, the time of excitation varies as well. For example, the points of highest velocity and displacement for the maximal overhang is right between the ones for the central and minimal overhang. A possible explanation for this behaviour would be the higher inertia of the first one.



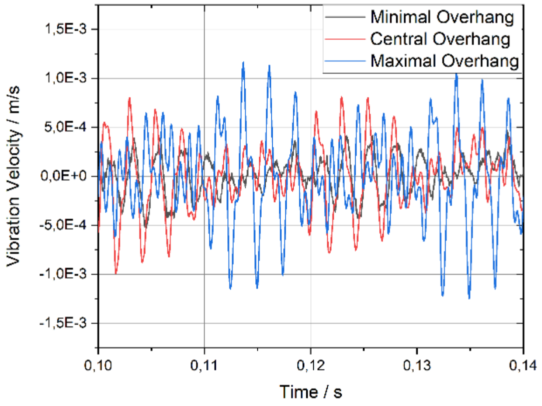


Figure 5: Measured vibrational velocity (bottom) as well as the calculated horizontal displacement (top) for three different parts of the overhang section of an electrode. The values were obtained for a power level of 17.4 kW/m.

Table 1: Comparison of Simulated and Measured RMS Values

	Overhang	**Inter-stem**
simulated displacement / m	2.4×10^{-7}	4.4×10^{-8}
measured displacement / m	1.4×10^{-7}	3.5×10^{-8}
simulated velocity / m/s	4.5×10^{-4}	9.1×10^{-5}
measured velocity / m/s	4.5×10^{-4}	1.8×10^{-4}

To better compare the results from simulations with the conducted measurements, the RMS values of them have been calculated and are shown in Table 1. In both cases, the simulated displacements surpass the measured ones. For the velocities, the simulated and measured RMS values for the overhang are an exact fit. Sadly, this cannot be said about the equivalent values for the inter-stem section. Nevertheless, accounting for the needed approximations in the simulations regarding how the force was implemented, the results are surprisingly close together.

CONCLUSION AND OUTLOOK

With the help of an advanced laser vibrometer, it was possible to measure the RF-power induced vibrations of the electrode in a situation of high-power conditioning.

Additionally, several simulations were conducted to test their ability to predict the amplitude and frequency of these vibrations. To be able to conduct those in a reasonable time span several approximations in terms of the application of the force must be made. These, of course, change the reliability of the simulation results. Keeping this in mind, it is remarkable how close some of the simulation results are to the experimental values. Especially regarding the velocity of the overhang and the displacement of the inter-stem section, where the deviations are very small. Contrary to that, the deviations between simulated and measured deviations of the overhang and the velocities of the inter-stem section are roughly 50 %. But even in these cases, the simulations are appropriate to estimate the rough order of displacement and vibration velocity.

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