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HIGH POWER TESTS OF A NEW 4-ROD RFQ WITH FOCUS ON THERMAL STABILITY

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Abstract

Due to strong limitations regarding operational stability of the existing HLI-RFQ a new design and prototype were commissioned. Three main problems were observed at the existing RFQ: A strong thermal sensitivity, modulated reflected power, and insufficient stability of the contact springs connecting the stems with the tuning plates. Although the last problem was easily solved, the first two remained and greatly hindered operations. 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, high power tests with more than 25 kW/m were performed at GSI. During those, it was possible to demonstrate operational stability in terms of thermal load and mechanical vibrations, calculating the thermal detuning, and proof the reliability of the proposed design.

INTRODUCTION

In 2010, a new 4-rod RFQ had been commissioned and integrated into the existing High Charge State Injector (HLI) at GSI [1].

Shortly after the implementation, several problems occurred. Those included the contact springs between the tuning plates and stems, periodically reflected power due to mechanical oscillations of the electrodes, and a high thermal sensitivity. Even though the first one could be resolved rather quickly, the mechanical oscillations and thermal sensitivity posed big challenges for the operator, since only several pulse lengths were accepted by the RFQ, and thermal detuning limited the possible power increase. [3]

To overcome those problems and ensure stable operation conditions, the development of a new RFQ was commissioned. This RFQ was optimized in terms of mechanical vibration suppression as well as efficient cooling while still reaching the set goals for power efficient acceleration. [2, 4]

To test the success of the proposed design, a prototype had been constructed. This shorter RFQ with an electrode length of roughly one fourth of the final design had been conditioned up to high power levels. During this process, mechanical observations had been performed as described in [5], to verify the success in terms of reduced mechanical vibrations. Additionally, the heating had been carefully observed as well as compared to simulations.

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EXPERIMENTAL SETUP

A schematic depiction of the experimental setup is shown in Figure 1. Overall, the setup was divided into two parts: The bunker with the RFQ, tuner, and sensors; and the RF-gallery with the RF-sender (see Figure 2), power meter, and observation station. Especially to mention is the fact that the tuner was manually controlled through a voltage source.

Even though the RFQ was designed for CW-capable usage, due to restrictions by the sender the maximum pulse length was 6.5 ms in a 20 ms interval.

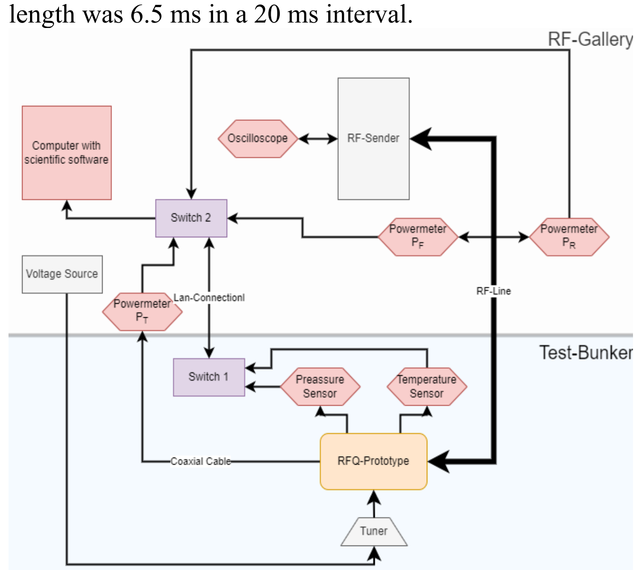

Figure 1: Schematic depiction of the experimental setup at GSI Darmstadt.

CONDITIONING PROCESS

Usually during RF conditioning, the power inside the cavity is slowly increased. Several conditioning effects, as multipathing, degassing, and flashovers, pose great threads to the conditioned cavity as well as the used equipment. This makes conditioning in most cases a time intensive and complicated endeavor.

Figure 2: RF-Sender used.

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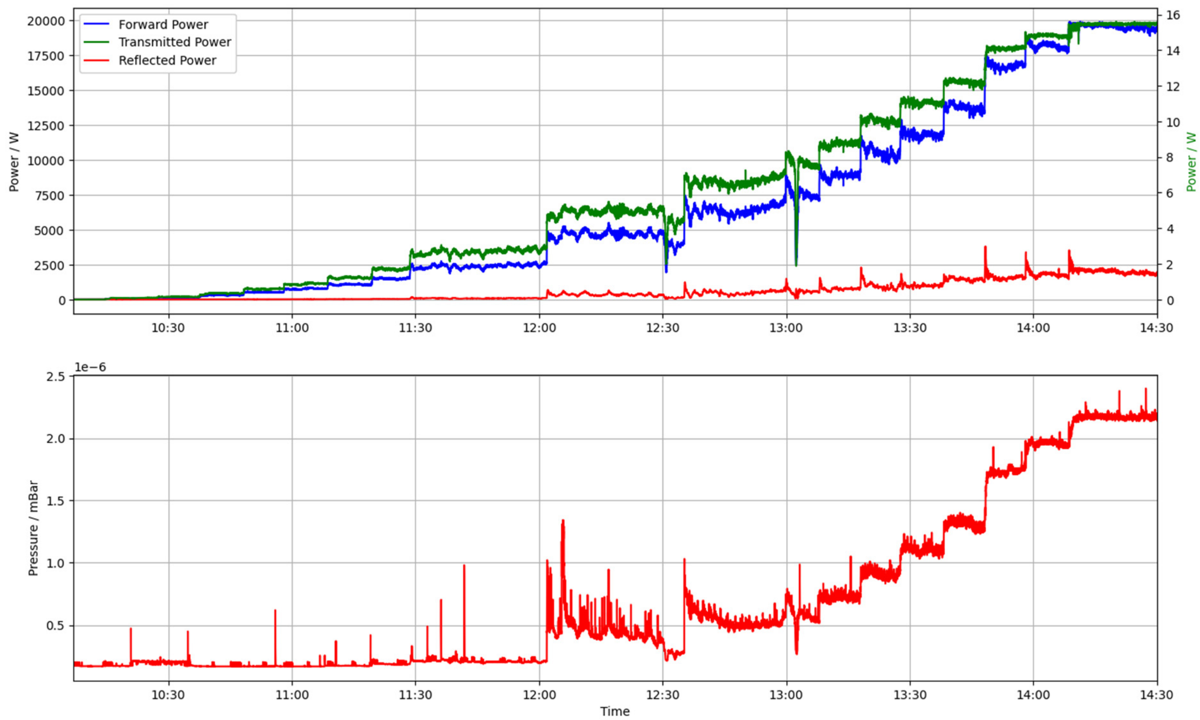

Figure 3: Conditioning process from 0 W up to 20 kW median forward power.

RF Conditioning

The RFQ was preconditioned at the IAP in Frankfurt [4], so that many problems, typically encountered in the low energy area, were quickly resolved. To achieve maximum median powers, most of the conditioning was performed using the maximum available pulse length. Additionally, to test the maximum inter-vane voltage possible, a pulse length as short as of 2 ms had been used. Using this setup, peak powers of 86.8 kW were reached, corresponding to an inter-vane voltage of 116.8 kV.

The maximum achieved values for a pulse length of 6.5 ms are presented in Table 1. There, the results are also compared to the target values which had been calculated by scaling the final design values to the length of the prototype.

To verify the capability of the prototype to accept all power levels, a final conditioning process from 0 W to roughly 20 kW forward power had been performed (see Figure 3). For this procedure, the power had been increased in steps as small as possible, and every power level has been held for several minutes to make sure the cavity reaches thermal equilibrium and no anormal effects take place. This was achieved without major issues, as can be seen in the depicted graph. The two visible power drops at around 12:30 and 13:00 were caused by either a too slow or wrong driving of the tuner, and thus were caused by the experimenter themself. In both cases the former power level was restored quickly and without any issues.

Thermal Analysis

A large problem regarding the old HLI RFQ was its sensitivity to thermal detuning [3]. To overcome this problem, huge effort was made to ensure an efficient cooling within the new design.

Table 1: Targeted values, derived from the final design, compared to values achieved during conditioning of the prototype. Depicted values were measured for the maximum pulse length of 6.5 ms.

	Final Design	**Prototype**
Dissipated Power [kW}	10.3	17.8
Dissipated Power per length [kW/m]	14.7	25.4
Inter-vane Voltage [kV]	40	92.7

The heating of several components of the RFQ during a conditioning process from 0 to 25.4 kW median dissipated power is shown in Figure 4. Regarding all components, the electrodes and stems heated the most. The unevenly heating of the different components have two reasons: First, the dissipated power is not the same for every component. For the stems this largely depends on their position inside the RFQ. The farther the stem is from the center of the RFQ, the less power is dissipated. For the electrodes, more power is dissipated on the lower ones. Combining this with the measured water flow through the cooling channels and estimating the transferred heat to adjacent components, the difference between the estimated and measured heating is inside the expected error range.

To measure the thermal detuning, the usual procedure is to compensate the detuning with the tuner and then examine the tuner detuning for the corresponding position. Here, due to the manual control of the tuner, the exact position was unknown. To resolve this problem, the tuner had been

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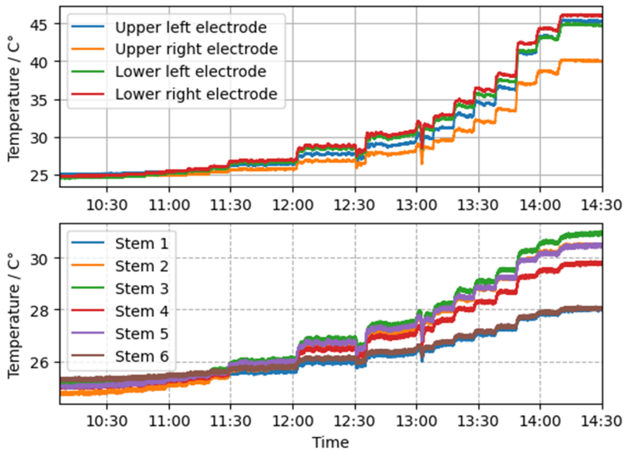

Figure 4: Measured cooling water temperatures for selected points, corresponding to the RF conditioning depicted in Figure 3.

held static while the power was stepwise increased. A controlled detuning was the result. Using the coefficient between reflected and forward power,

$$\Gamma(\omega) = \frac{\beta - 1 - i\beta Q_0 \delta}{\beta + 1 + i\beta Q_0 \delta}, \quad (1)$$

where β is the coupling factor, Q_0 the quality factor and

$$\delta = \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}, \quad (2)$$

with the frequency ω and reconance frequency ω_0, the detuning can be calculated. Since the power had been increased in eleven steps, eleven clusters of measuring points are the result as shown in Figure 5. Those clusters can be fitted, with the slope as thermal detuning per power.

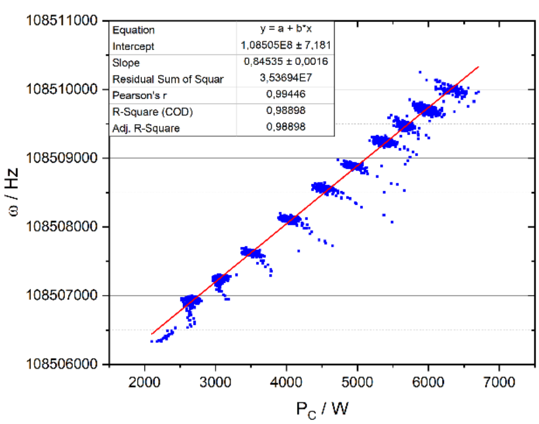

Figure 5: Calculated thermal detuning of the RFQ prototype.

CONCLUSION AND OUTLOOK

The acceptance of a multiple of the desired power per length as well as inter-electrode voltage was demonstrated. Additionally, it was possible to calculate the thermal detuning of the RFQ prototype, even though the exact position of the tuner was unknown. In combination with the increased mechanical stability, which is discussed in [5], it is possible to say that the new design overcomes all issues the old HLI RFQ encountered.

Overall, the process worked, after some initial problems with the setup, very smooth, and no major problems were encountered.

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