ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR08

# IMPROVEMENTS TO 4-ROD RFQS WITH ADDITIVE MANUFACTURING PROCESSES

J. Storch*[1], E. Boos[3], P. Braun[1], H. Hähnel[1], H. Podlech[1,2], K. Kümpel[1]
[1]Goethe University, Frankfurt, Germany
[2]Hesse for FAIR (HFHF) Campus Riedberg, Frankfurt, Germany
[3]Gesellschaft für Schwerionenforschung, Darmstadt, Germany

*Abstract*

The institute of applied physics (IAP), at the university of Frankfurt, has been working for years on the development of increasingly powerful 4-rod RFQ accelerators for hadron acceleration. The need for such accelerators has risen significantly in the recent past, as accelerator-driven neutron sources are becoming more important following the closure of various test reactors in Europe. High beam currents, high particle energies and operational stability are often required from those LINACs. In order to meet these requirements, adding more advanced cooling channels in the copper structure of the RFQ, with a new type of pure copper 3D-printing, will be explored. Comprehensive multiphysics simulations with Ansys, d'Assault CST and Autodesk-CFD will first be carried out to evaluate the operational stability and performance.

## INTRODUCTION

The current design of the 4-rod RFQs at IAP has been developed for the Frankfurt Neutron Source (FRANZ) [1] and is also found, in adapted form, in the RFQ of the MYRRHA LINAC [2] at SCK•CEN. Furthermore it is intended to be used for the two RFQs of the High Brilliance Neutron Source (HBS) at the Forschungszentrum Jülich [3]. Within the design power of the above-mentioned projects (under 30 kW/m, this design works flawlessly [4]. However, increasing the design power can reduce the length of the RFQ in future projects, potentially leading to beam dynamic advantages and cost reduction. The functioning principle of a 4-rod RFQ as a line resonator allows for the production of a prototype with fewer stems and a correspondingly shorter length. With a 4-stem prototype of the current 4-rod design, representative performance tests well above the design power have been conducted. It was found that thermal instabilities occur at a power of 75 kW/m as seen in Fig. 1. After the power was increased further to 150 kW/m, severe thermal problems were observed at the contact points between the tuning-plates and stems [5]. To increase the power even more through improved cooling and to prevent problems with the tuning-plate contacts, additive manufacturing with pure copper appears to be a suitable solution. To verify this technique, the copper structure of the 4-stem prototype will be replaced by a new optimised structure produced using additive manufacturing techniques and its performance will be compared to the conventionally manufactured prototype.

* storch@iap.uni-frankfurt.de

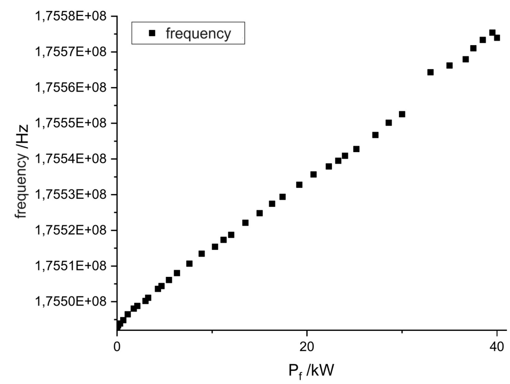


Figure 1: Frequency shift during high-power conditioning of the 4-stem prototype with an electrode length of 392 mm [5].

## CURRENT DESIGN AND ITS LIMITATIONS

The thermal analysis was conducted on the 4-stem FRANZ prototype, revealing thermal bottlenecks in the upper part of the stems, with temperatures reaching up to 476 K, as identified through Ansys [6] simulations (see Fig. 2). It is crucial to keep the temperature below 400 K to prevent outgassing [4]. Additional thermal problems were observed at the tuning-plate stem transition, where melting and welding of the plate occurred after high-power tests. These issues were not predicted by simulations, as the transition resistances were not considered in d'Assault CST [7] simulations, which were used to simulate surface losses before importing them into Ansys.

## 3D-PRINTED DESIGN

The geometry of the additively manufactured structure closely resembles that of the existing prototype to ensure good comparability. Improvements in operational stability are aimed to be achieved by implementing more sophisticated cooling channels, enhancing thermal performance. Figure 3 shows the simulated surface temperature of a 3D-printed stem at a power loss of 60 kW.

Despite the increased power, the maximum surface temperature reaches only 354 K. It should be noted that the simulation did not account for the water-pipes of the electrode cooling running through the stems, which should further reduce the temperature at the shown hotspot. A comparison of the cooling channels between the existing and the new

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR08

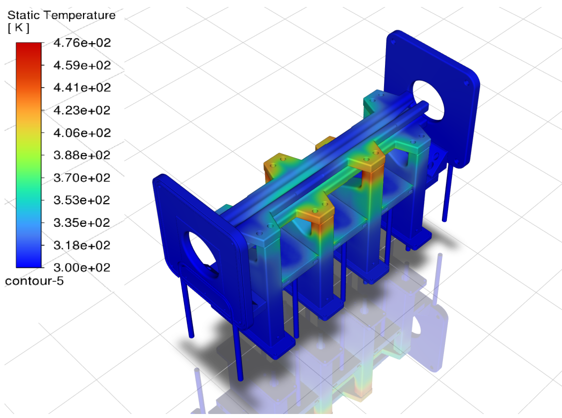


Figure 2: Simulated surface temperatures at 50 kW (127.5 kW/m) of the current RFQ-Prototype using Ansys fluent 2023R2.

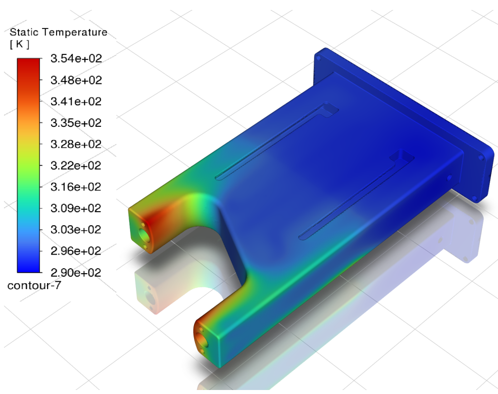


Figure 3: Simulated surface temperatures at 60 kW (153.1 kW/m) of the proposed 3D-printed RFQ-stem using Ansys fluent 2023R2.

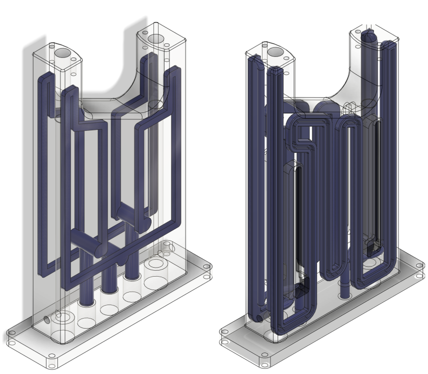

Figure 4: Comparison of the cooling channels of the conventionally manufactured stem (left) and the 3D-printed stem (right).

design can be seen in Fig. 4, highlighting the improvements made in the new design.

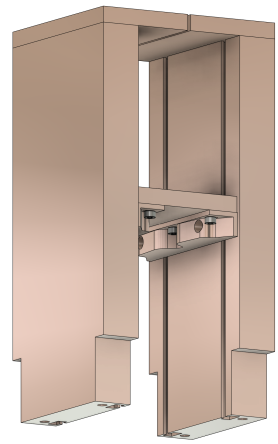

Figure 5: CAD-model of the tuning-plate-test-stand currently in production

## PRE-TESTS

Before construction of the additively manufactured structure begins, several preliminary tests are still to be carried out.

### *Testbench for a New Tuning-Plate*

To better utilize the capabilities of additive manufacturing, the tuning-plate mounting has been redesigned. In the new design, the tuning-plates are not clamped as in the old design; instead, they are attached using screws and T-slots in the stems, allowing for better cooling of the contact area and promising to reduce the transition resistance. Additionally, the process of flatness tuning is expected to become less cumbersome. To test these modifications, a significantly simplified two-stem model is currently being fabricated (see Fig. 5) using conventional methods. This model will be installed in a vacuum tank to test the user-friendliness of adjusting the tuning-plate height. Furthermore, it will allow for the determination of contact resistance through Q-factor measurements and enable a comparison with the old style of tuning-plate mounting.

### *Erosion Test*

Erosion corrosion describes the process in which copper channels are damaged due to the simultaneous effect of mechanical wear and chemical corrosion. This process occurs in metal pipes where water is used as a coolant. The combination of oxide removal due to flow acceleration and new oxidation of copper by the cooling water leads to continuous material removal, as seen in Fig. 6.

Currently, there is no data available on the behavior of 3D-printed copper in cooling water circuits. Therefore, a specific test must be designed to determine the boundary conditions for the channel geometries ensuring the long-term durability of the RFQ. For this purpose, a test geometry will be created and circulated with water in the IAP's cooling system for several months. By measuring the material removal and

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPR08



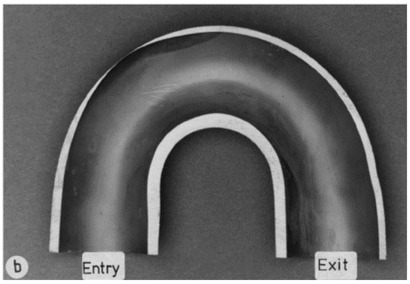

Figure 6: Damage pattern in a copper pipe worn by erosion corrosion. The elbow previously had a uniform diameter [8].

simulating flow conditions, conclusions can be drawn about the maximum permissible turbulence and velocity.

## SUMMARY

Initial simulations show very promising results in reducing negative temperature effects through the use of additive manufacturing in the production of 4-rod RFQs. Additionally, a 3D-printed design is expected to be more cost-effective. However, the question of suitable surface treatment remains open. Further research is needed in this area to ensure the performance of the RFQ. It needs to be clarified whether the printed copper fulfills the necessary vacuum and conductivity requirements after printing and polishing, or whether CNC-machining and/or galvanic copper plating should be carried out.

## ACKNOWLEDGEMENTS

This work was supported by the ”Forschungszentrum Jülich”.

## REFERENCES

[1] U. Ratzinger *et al.*, “The Frankfurt neutron source FRANZ”, in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper MOPEC059, pp. 597–599.

[2] H. Podlech *et al.*, “The MYRRHA-RFQ - status and first measurements”, in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 2243–2245. doi:10.18429/JACoW-IPAC2017-TUPVA071

[3] R. Gebel, A. Lehrach, H. Podlech, “Technical Design Report HBS”, vol. 1 - Accelerator, ISBN 978-3-95806-709-7, 2023. https://www.fz-juelich.de/en/jcns/jcns-2/expertise/high-brilliance-neutron-source/conceptual-and-technical-design

[4] K. Kümpel, “Untersuchungen am MYRRHA Injektor”, Dissertation, Goethe University, Frankfurt, 2022 doi:10.21248/gups.68892

[5] A. Rüffer, “High-Power-Test des 175 MHz RFQ Prototypen”, Master Thesis, Goethe University, Frankfurt, 2022.

[6] Ansys, https://www.ansys.com/de-de/products/fluids/ansys-fluent

[7] CST, https://www.3ds.com/de/produkte-und-services/simulia/produkte/cst-studio-suite

[8] B. Poulson, “Complexities in predicting erosion corrosion”, *Wear*, vol. 233–235, pp. 497–504, Dec. 1999. doi:10.1016/s0043-1648(99)00235-5