Additive Manufacturing of Copper and Copper-Alloy 4-Rod RFQs with Gyroid-Enhanced Cooling for High-Power CW Operation #THOP007

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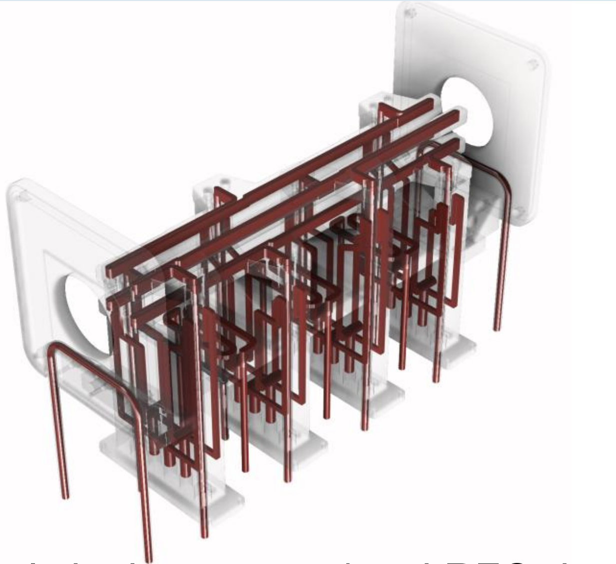
4-rod RFQs at IAP Frankfurt

MYRRHA-RFQ for SCK•CEN in Belgium

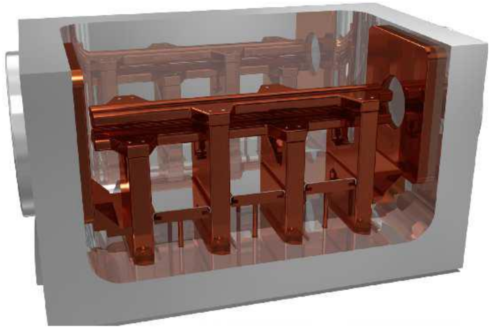
Parameter	FRANZ RFQ	MYRRHA RFQ
Frequency	175 MHz	176.1 MHz
Electrode length	1.75 m	4.0 m
Duty cycle	up to 100 % (cw)	up to 100 % (cw)
Beam current	up to 200 mA (protons)	up to 5 mA (protons)
Electrode voltage	75 kV	44 kV
RF power	150 kW	110 kW
Power per length	**86 kW/m**	**28 kW/m**

- The 4-rod RFQ was originally developed at IAP in Frankfurt.
- IAP has supplied RFQs for projects worldwide over the years.
- The 4-rod RFQ design has been continuously improved over time.
- The latest design is used for the RFQs of the FRANZ and MYRRHA projects.
- A 4-stem prototype of this design is available for experimental studies.



Cooling channels in the current 4-rod RFQ design

Channels are milled into the copper and subsequently closed with thick copper plating.



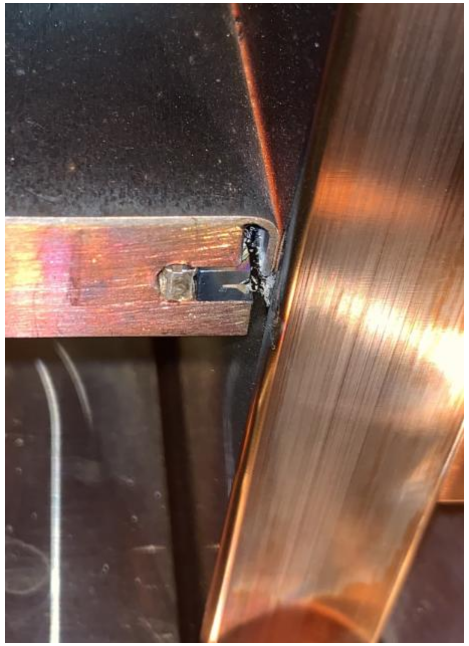
4-stem prototype of the current 4-rod-rfq-design

Electrode length: 400 mm

High power, high duty cycle RFQs

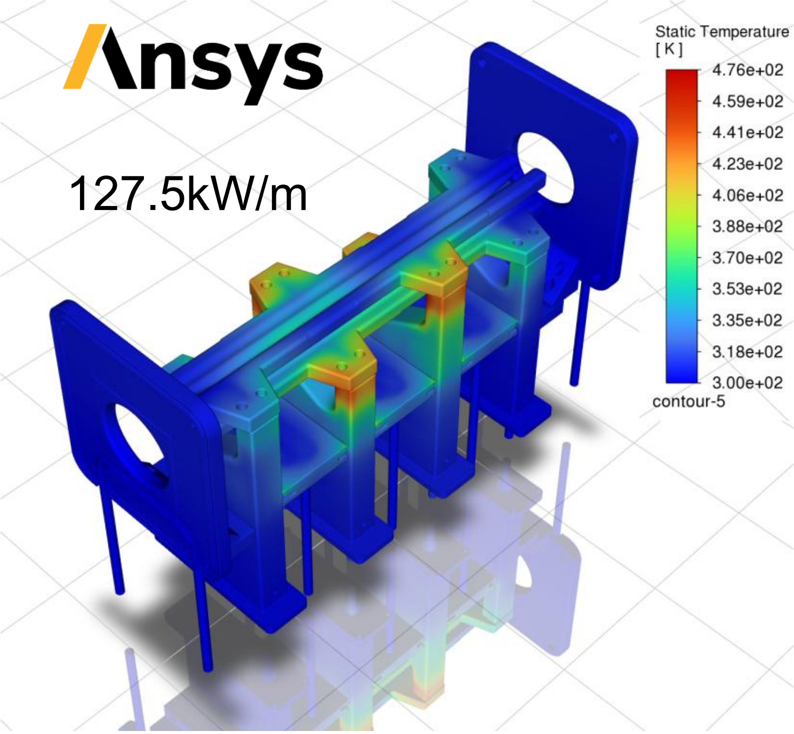
- High power high duty cycles are gaining more importance in the current years, especially for accelerator driven neutron sources and fusion experiments
- The 400mm 4-stem prototype was tested up to around 150 kW/m
  - Result: Current design will start to get irreversibly damaged above 120kW/m

Results of the post test inspection:

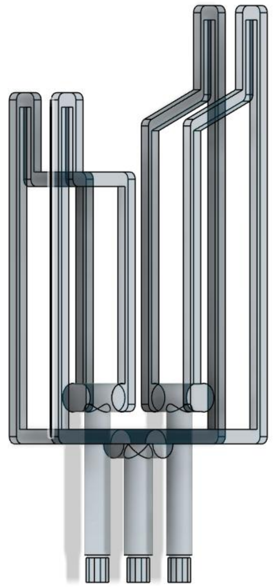


Damage on the stem tuning plate interface

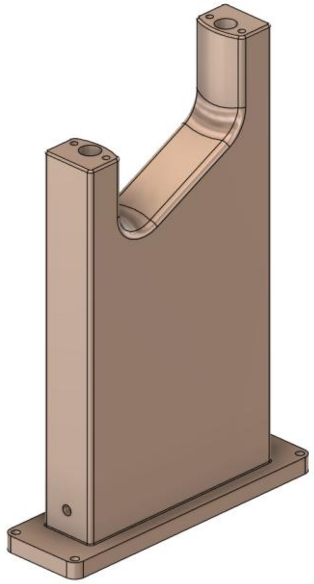
Thermal discoloration



Improvement: L-PBF printed stem



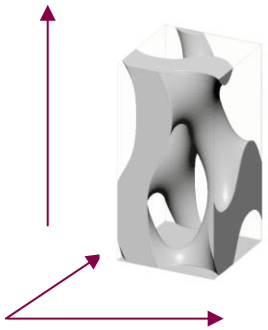
Current cooling layout



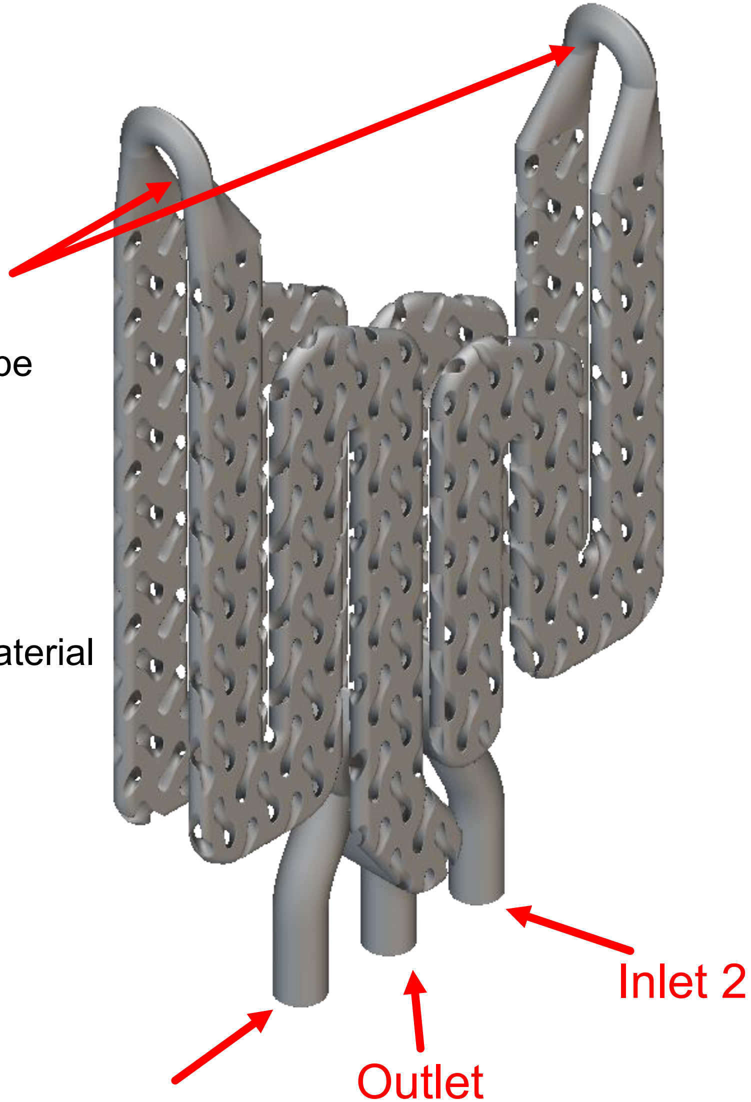
Outer shape remains unchanged for comparability

Teardrop-shape for printability

Z = 15 mm
40 : 60 water / material



X = 10 mm

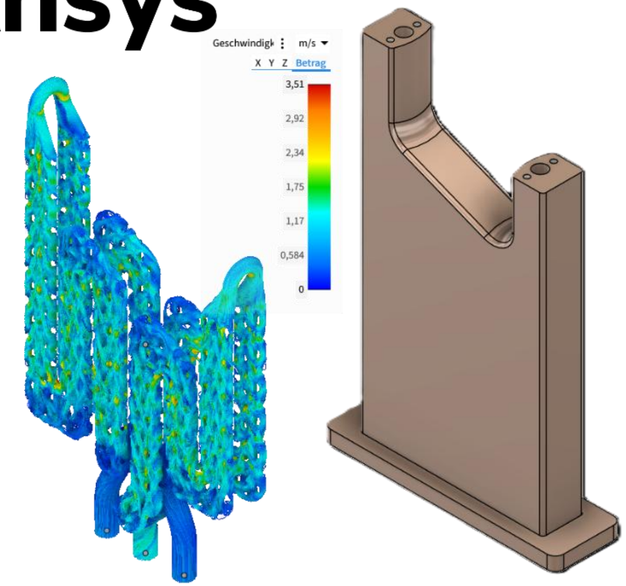


Cooling channel of printed stem

Why a gyroid?

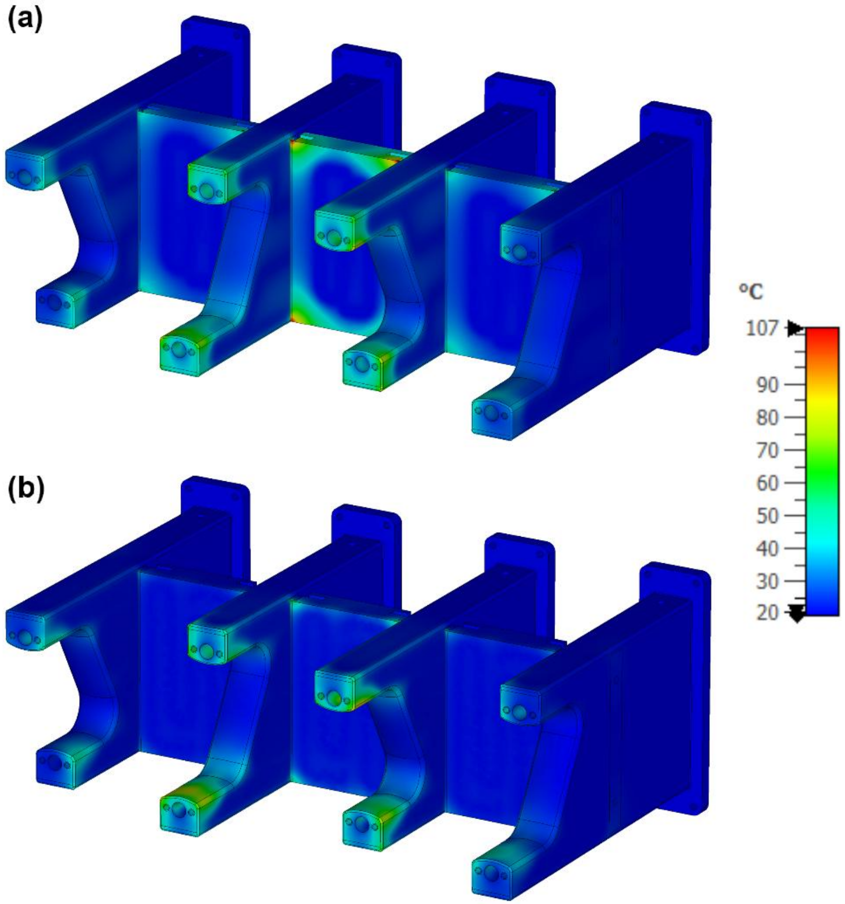
- Significantly Increased water-material-interface surface
- Gyroids can be printed in any direction and make the cooling channels self supporting.
- Increased mechanical stability
- Increased turbulences and therefore heat transfer to the water

Flow simulation of printed stem



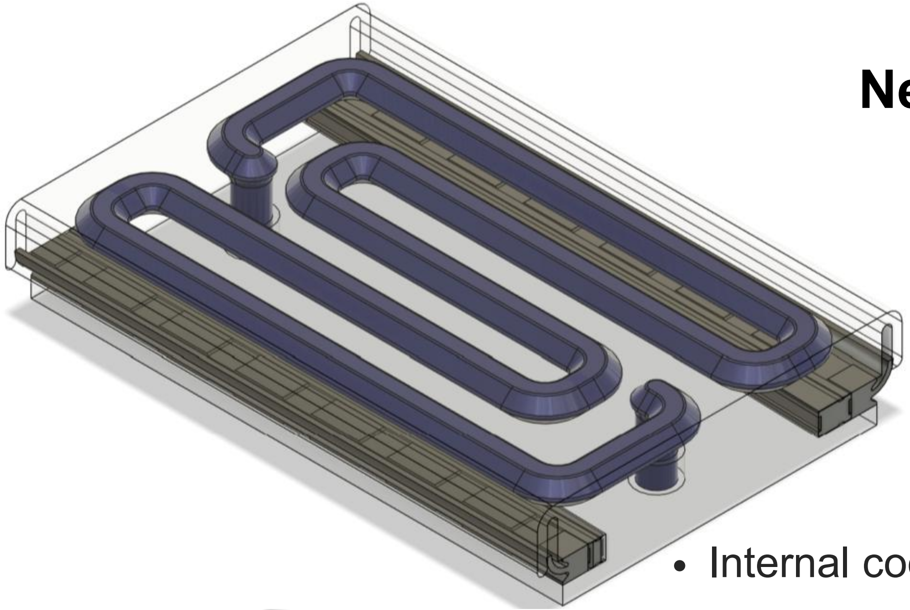
Fluid simulation in ANSYS Discovery with 3.5l/min per channel (7l/min overall)

Flowrate determined by testing of a printed polymer model of the stem

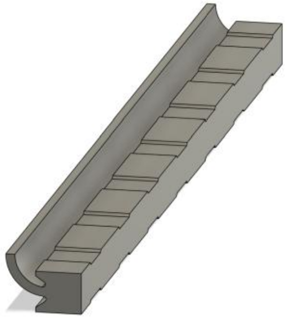


CST solid state thermal simulation of
a) Conventionally manufactured cooling geometry
b) Additively manufactured cooling geometry
Simulated at 125 kW/m

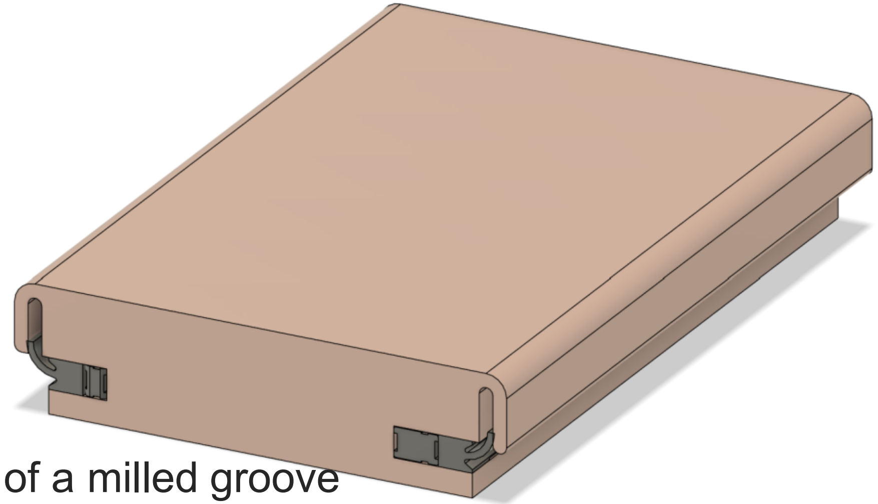
Upgraded tuning plate



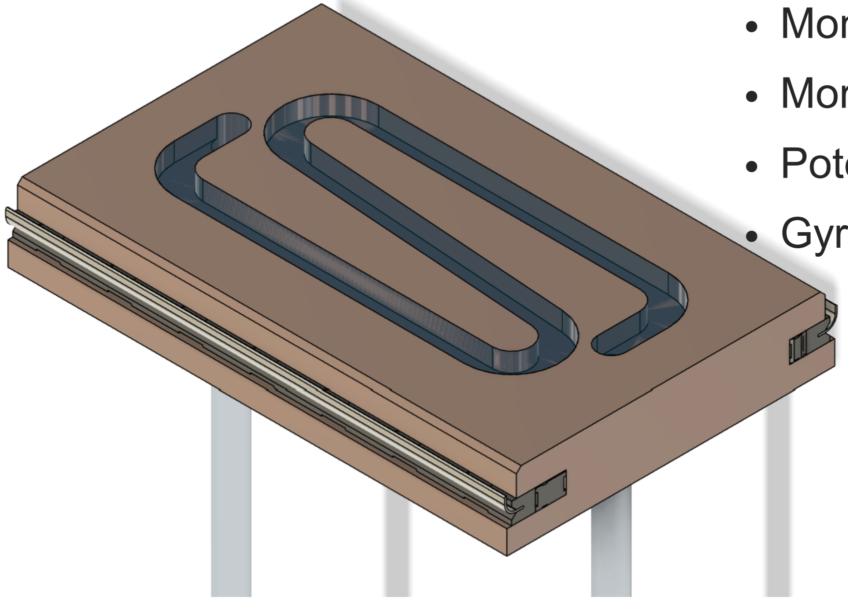
New revision



Spring printed from L-PBF 304L



- Internal cooling channel by L-PBF instead of a milled groove
- Monolithic design, improves thermal performance
- More cost effective
- Potentially better electrical contact
- Gyroidal cooling structures not suited for this application



Current design

Copper block with silver plate

Status and Outlook

- Currently in manufacturing:
  - 4 + 1 CuZr stems with 1 mm copper plating, machined and polished
  - 4 + 1 pure-copper stems, machined and polished
  - New pure-copper tuning plates, machined and polished
- Next steps:
  - High-power test of the 4-stem prototype with both sets of upgraded parts up to 60 kW (150 kW/m) this year
  - One stem per material in a long-term water test (approx. 1 year of continuous flow), then cut open and inspected for erosion
- Outlook:
  - Transfer of successful elements to future projects such as HBS-I
  - Optimization of the electrodes