UPDATE ON THE EUROPEAN XFEL RF POWER INPUT COUPLER.

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Abstract

The European XFEL project [1, 2] is currently being realized in Hamburg, Germany. The 1.5 km 17.5 GeV linear electron accelerator is based on the 1.3 GHz 9-cell TESLA type SRF cavity. The RF power input coupler design for the E-XFEL (fig.1) is based on the well-known TTF3 [3, 4] coupler design, used in the FLASH accelerator at DESY. The coupler design was adapted for industrial production with some parameters optimization revisited and simulations done.

INTRODUCTION

Industrialization process for European XFEL RF power input coupler was described in [5] and resulted in a well-established and robust design (fig.1). A need for additional adjustments and analysis did appear recently following the start of production of the industrialized coupler. One of the important topics is the copper coating of the coaxial part of the coupler. Thermal analysis yields the temperature distribution along the coupler and the cryogenic loads for the thermal zones (2, 4.2 and 70 K). Table 1 lists the well known specifications of the coupler.

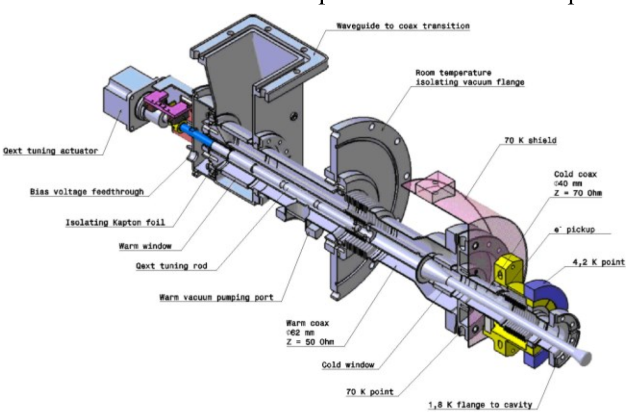

Figure 1: XFEL RF power input coupler.

Table 1: RF Power Coupler Specifications.

	FLASH	ILC	XFEL
frequency [GHz]	1.3		
operation	pulsed: ~500 µs rise time, ~800 µs flat top with beam		
2.0 K heat load [W]	0.06		
4.2 K heat load [W]	0.5		
70 K heat load [W]	6		
peak power [kW]	250	400	150
rep. rate [Hz]	10	5 / 10	10
average power [kW]	3.2	3.2 – 6.4	1.9

The XFEL coupler design is based on the TTF3 coupler and its thermal analysis done with mafia [6] / MathCAD [7] simulation codes using a simplified 2D model of the coaxial part (fig. 2). Details of the simulations and some thermal analysis data for the TTF3 coupler are presented in [8]. Simulations assume perfect connection to 4.2K and 70 K for the outer conductor. The inner conductor is connected to the 70 K through the ceramic window.

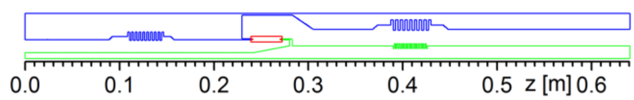

Figure 2: XFEL/TTF3 coupler simulation layout.

MATERIAL PROPERTIES

Material properties data for the thermal conductivity are taken from NIST Cryogenics Technologies Group data base [9]. Electrical conductivity data are obtained with Bloch-Grueneisen theorem [10-12]. Material data cross check is done with different sources [13-16]. New data used for this particular simulation are thermal and electrical conductivity of copper and gold vs. temperature and with different RRR (for copper) are shown on fig.3 and fig. 4.

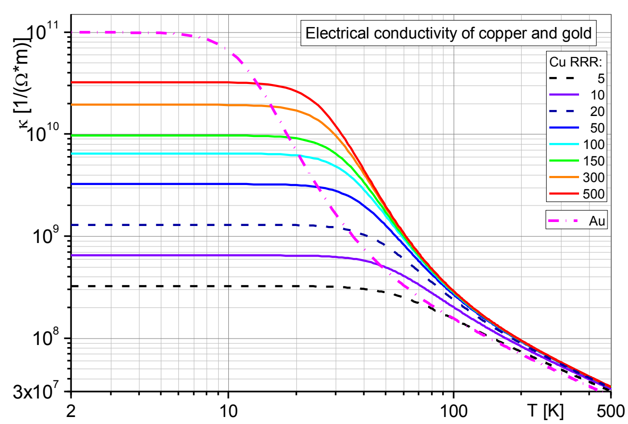

Figure 3: Electrical conductivity of copper and gold.

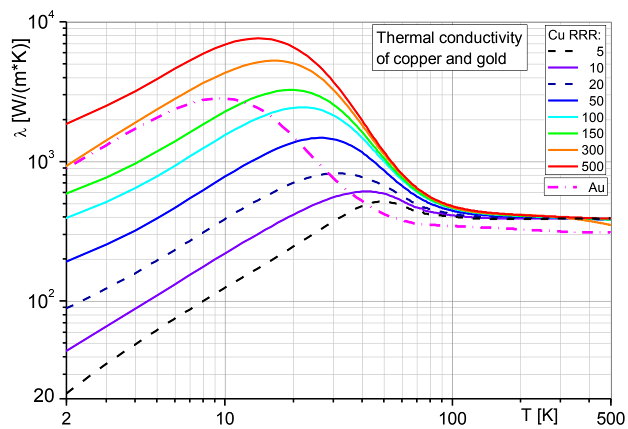

Figure 4: Thermal conductivity of copper and gold.

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THERMAL ANALYSIS DATA

RF power is simulated up to 5 kW (effective average CW power). For the XFEL the effective average CW power is near 2 kW.

Copper Layer RRR Variation.

XFEL / TTF3 coupler thermal simulations are done with different copper RRR (fig.5 - 9).

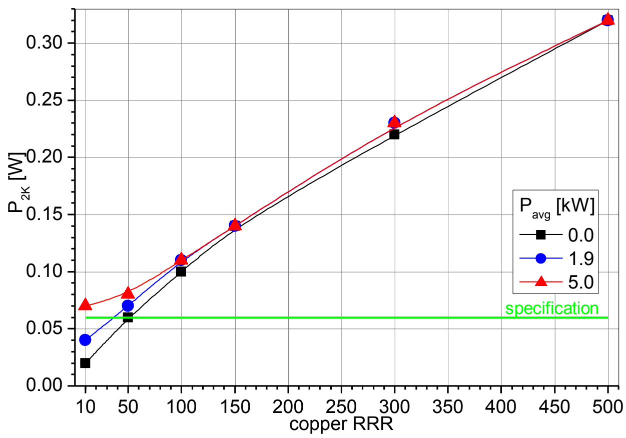

Figure 5: 2.0 K heat load with copper RRR.

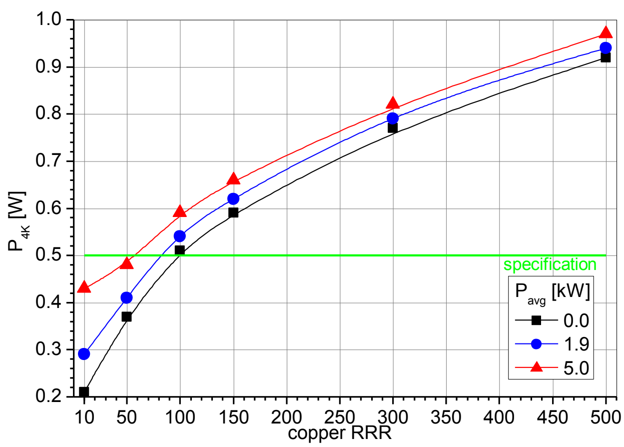

Figure 6: 4.2 K heat load with copper RRR.

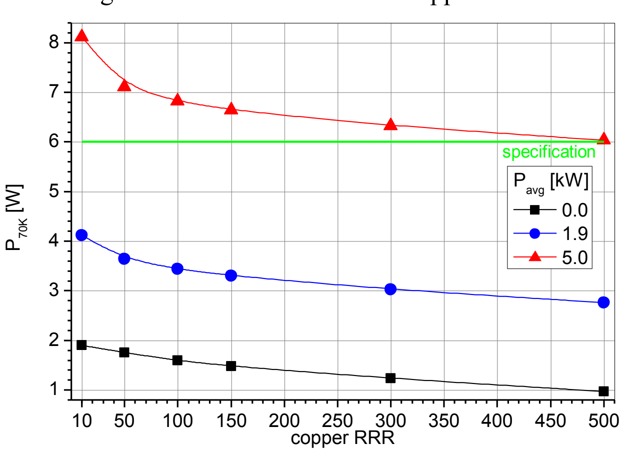

Figure 7: 70 K heat load with copper RRR.

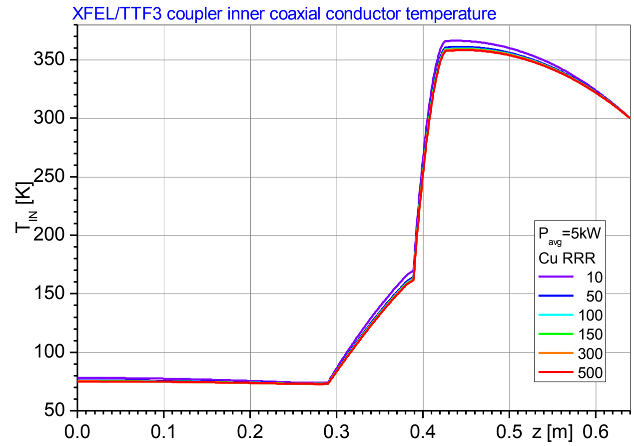

Figure 8: Inner conductor T(z) with copper RRR.

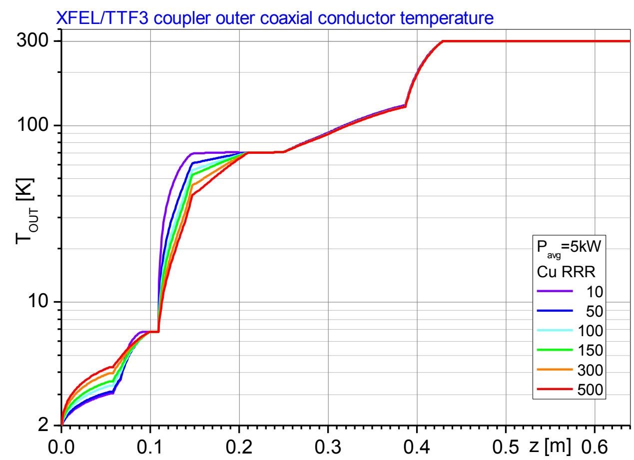

Figure 9: Outer conductor T(z) with copper RRR.

Simulations show that static cryogenic losses play a major role. Copper coating RRR is limited by a maximum of 50 with 2 K zone cryogenic losses specified by maximum of 0.06 W. This RRR limit is applied to the cold outer conductor only. The inner conductor contributes mostly to 70 K zone and its RRR is not limited. The warm part copper RRR is also not limited.

No Copper Layer on the Outer Conductor.

The idea of not using a copper coating on the whole outer conductor was proposed and investigated. Stainless steel without copper layer was simulated on the outer conductor. The inner conductor was simulated with a 30 µm copper layer (RRR=10). The thermal analysis data in Table 2 and fig.10 show that it is not feasible within the specified cryogenic load budget. In addition serious overheating because of dynamic load with higher RF power will occur and limit the coupler performance, as seen in fig.10 presenting the outer conductor temperature distribution along the coupler.

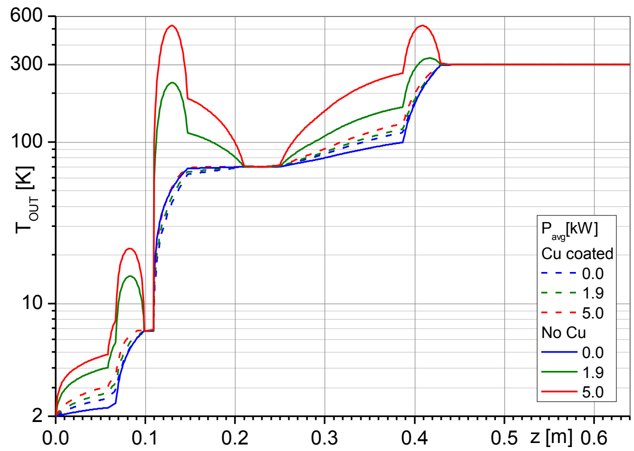

Figure 10: Outer conductor T(z) without copper layer.

Table 2: Cryo-loads for the Input Coupler with and without a Copper Layer on the Outer Coaxial Conductor.

P_{avg}	P Σ	P Σ	P in	P out	P win	P Σ
	2K	4K	70K			
kW	W					
standard design						
0.0	0.02	0.21	0.84	1.06	0.00	1.90
1.9	0.04	0.29	2.25	1.50	0.37	4.12
5.0	0.07	0.43	4.88	2.26	0.97	8.11
no copper layer on outer conductor						
0.0	0.008	0.03	0.84	0.59	0.00	1.43
1.9	0.31	1.42	2.29	5.99	0.37	8.65
5.0	0.81	4.13	5.37	15.94	0.97	22.28

Thin Gold Layer on Cold Outer Conductor.

Another coupler design with 1 µm gold coated cold outer coaxial conductor was analyzed. Such coating is technologically simpler compared a copper coating. Table 3 summarizes the cryogenic loads for the different average power levels and in fig.11 and fig.12 temperature distributions are presented. The warm part outer conductor was simulated with 10 µm RRR=10 copper layer and the inner conductor with 30 µm and RRR=20. Simulations confirm that there is almost no change in the coupler thermal load parameters and no performance deterioration.

Table 3: Cryo-loads for the Input Coupler with 1µm Gold Coated Cold Outer Coaxial Conductor.

P_{avg}	P Σ	P Σ	P in	P out	P win	P Σ
	2K	4K	70K			
kW	W					
0.0	0.034	0.041	0.85	1.21	0.00	2.06
1.0	0.035	0.059	1.50	1.45	0.19	3.14
2.0	0.036	0.085	2.19	1.70	0.39	4.28
3.0	0.036	0.122	2.93	1.97	0.58	5.48
4.0	0.037	0.170	3.71	2.25	0.78	6.74
5.0	0.038	0.230	4.53	2.54	0.97	8.04

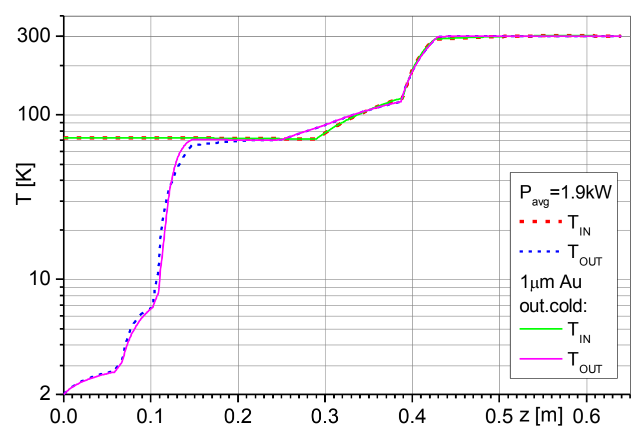

Figure 11: T(z) with 1µm gold on cold outer conductor.

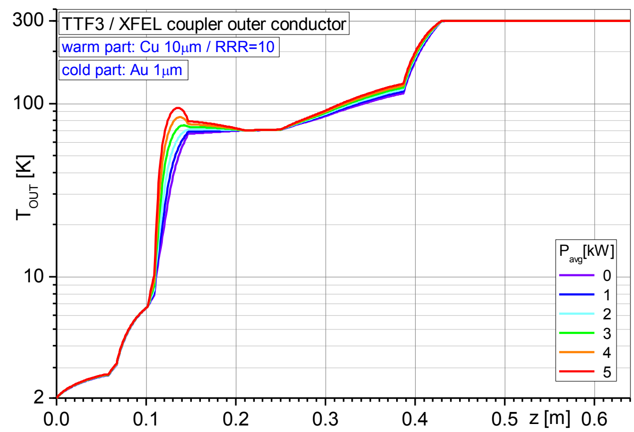

Figure 12: $T_{out}(z)$ with 1µm gold on cold outer conductor.

SUMMARY

- The XFEL / TTF3 RF power input coupler thermal simulations and analysis were done for certain design variations and parameter space.
- The copper layer RRR variation study is done from RRR 10 to 500. RRR upper limit of 50 is applied to the cold outer conductor only.
- The coupler outer conductor without copper coating was simulated. This design change would spoil the coupler performance with drastically increased dynamic cryogenic loads.
- A thin gold layer of 1 µm on the cold outer conductor applied instead of the copper coating has no negative influence on the coupler performance and could be used.

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