TTF-III COUPLER MODIFICATION FOR CW OPERATION*

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Abstract

LCLS-II linac is based on XFEL/ILC superconducting technology, but CW regime of operation requires the modification of components to satisfy LCLS-II requirements. TTF-III [1] coupler is considered as a candidate for a fundamental power coupler for the 1.3 GHz 9-cell accelerating structure at the LCLS-II project [2]. In this paper we discuss the results of multiphysics analysis of the coupler working at various operating regimes. Two major modifications are proposed in order to meet the LCLS-II requirements and eliminate possible overheating: reducing the length of antenna (cold part) and increasing the thickness of a cooper plating on the inner conductor of the warm part of the coupler.

INTRODUCTION

XFEL (modified TTF-III) fundamental power coupler doesn't not meet to the following LCLS-II requirements:

- The coupler tuning range doesn't cover the required nominal $Q_{ext} = 4.e7$
- There is an overheating of the internal bellow in the warm section of the coupler at 7 kW CW input power and full reflection (effective power ~14 kW)

Table 1: LCLS-II Coupler Technical Specs

Item	Spec
Design	EuXFEL Coupler
Max Input Power	7 kW CW
Minimum Qext Foreseen	1e7
Maximum Qext Foreseen	5e7
Reduction in Antenna Length	8.5 mm
Range of Antenna Travel	+/- 7.5 mm
Predicted Qext Min Range Qext Max Range	3.6e6 – 4.7e6 – 7.5e6 1.0e8 – 1.1e8 – 1.5e8
Warm Section Outer Cond Plating	10 um +/- 5 um, RRR = 30-80
Warm Section Inner Cond Plating	100 um +/- 10 um, RRR = 30-80
Cold Section Outer Cond Plating	10 um +/- 5 um, RRR = 30-80
Center Conductor HV Bias	Optional
Warm and Cold e-Probe ports req	No
Warm Light Port Required	No
Motorized Antenna	Yes – max step = 50 um
RF Processing	7 kW CW with full reflection – vary reflected phase by 180 deg

Two modifications were proposed to address these problems in a frame of the TTF-III coupler R&D and test program:

- Cut the antenna at 8.5mm for increasing the nominal Q_{ext} value.
- Increase the thickness of copper plating on the internal inner conductor of the warm section from 30 µm to 100-150 µm and eliminate overheating.

The main technical specs of the LCLS-II coupler are summarized in Table 1.

MODIFICATION OF ANTENNA

The proposed solution for matching the coupler tuning range is cutting of the antenna tip by 8.5 mm. Figure 1 shows geometries of the original TTF-III (up) and the modified coupler (down) antennas respectively.

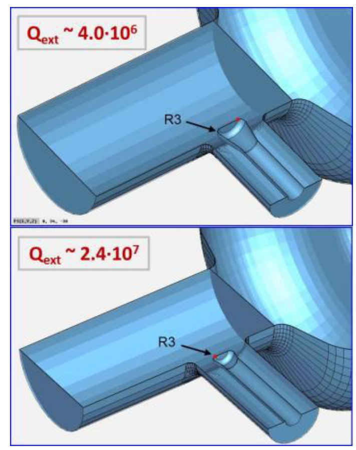

Figure 1: Original TTF-III antenna (up) and modified LCLS-II antenna (down), cut 8.5 mm, rounding is 3 mm.

The range of the antenna tuning displacement is supposed to be similar to the TTF-III coupler: ±7.5 mm. Figure 2 shows the dependence of Q_{ext} versus antenna offset from the cavity axis for the TTF-III and two proposed variants of modifications by cutting the antenna tip on 7 mm (red) and 8.5 mm (blue). Dashed line shows the nominal Q_{ext} value required by the LCLS-II specification.

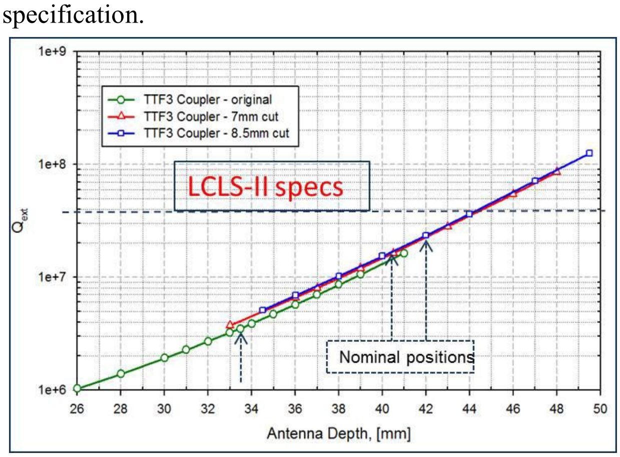

Figure 2: Q_{ext} vs. antenna depth. Green – original TTF-III coupler, red - cut 7 mm, blue – cut 8.5 mm.

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Table 2 summarizes the minimal, nominal and maximum values of external coupling in the tuning range of ±7.5 mm for the original TTF-III and modified couplers.

Table 2: Q_{ext} Values in Tuning Range

	Q_{min}	Q_{nom}	Q_{max}
Original coupler	1.10^6	$3.5{\cdot}10^6$	$1.8{\cdot}10^7$
Tip cut by 8.5mm	$5.0{\cdot}10^6$	$2.4{\cdot}10^7$	$12{\cdot}10^7$

MODIFICATION OF INNER CONDUCTOR

One of possible solutions in order to eliminate the overheating problem in the TTF-III coupler warm section is increasing the thickness of Cu plating on the outer surface of the inner conductor.

COMSOL simulations have been done for calculating temperature distributions in the TTF-III coupler for different thickness of Cu plating. Figure 3 shows the coupler solid model and boundary conditions used for the multiphysics analysis. Power losses calculated in the RF domain are used later for heat transfer simulations. Figure 4 shows the temperature distribution along the original TTF3 coupler for the following parameters: the input RF power is 7 kW, inner conductor is plated with 30 µm of Cu layer, and outer conductor is plated with 10 µm of Cu.

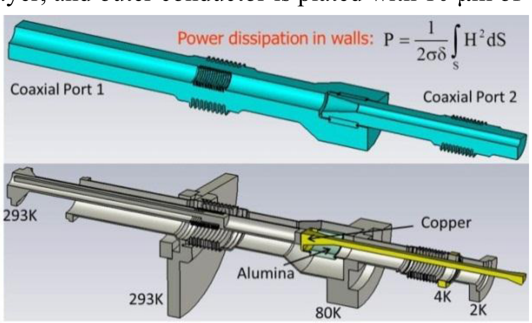

Figure 3: Two stages of COMSOL simulations. Up - RF domain, down- heat transfer domain.

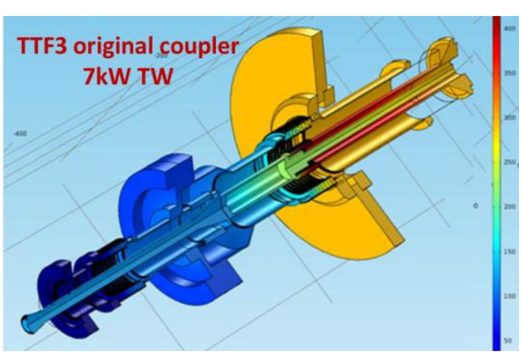

Figure 4: Temperature distribution vs. in TTF3 original coupler. P=7kW, inner Cu plating is 30 µm.

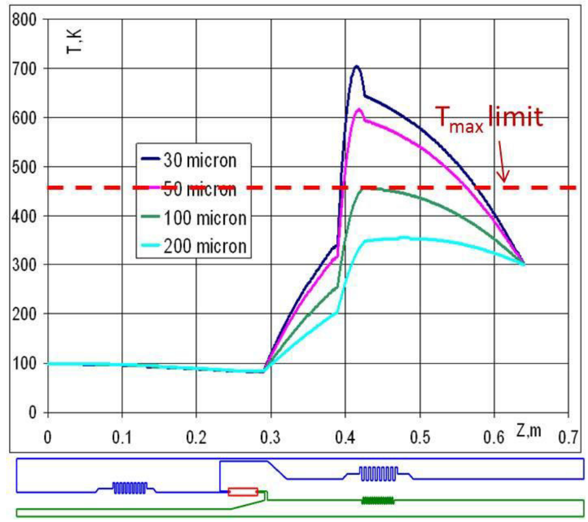

Figure 5: Temperature distribution vs. thickness of Cu plating.

Figure 5 shows the temperature distribution depending on the thickness of Cu plating. Simulations have been done for 15 kW input power and TW regime, RRR of plated copper is assumed 10. The dashed line shows the maximum allowable temperature limit of 450 K.

Simulations predict that increasing the thickness of Cu plating on the inner conductor to 100-150 µm is a possible solution for elimination an overheating.

During the coupler operation the actual temperature of the inner conductor will be measured with non-contact infrared temperature sensor mounted on a quartz window. A schematic view of the test setup is shown in Figure 6.

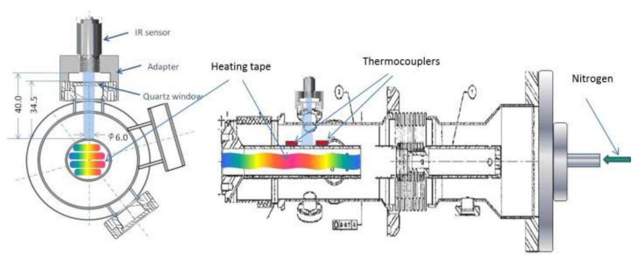

Figure 6: Schematic view of the test setup.

The sensor has 2.3 microns wavelength that allows minimizing emissivity errors and reading data through the original quartz window. The test measurements were performed with original Warm End Assembly at temperatures up to 400 K. Platinum thermocouples mounted directly on the copper plated tube are used for the temperature calibration. It was found that at emissivity setting of 0.6 the data from the infrared sensor and from the thermocouple are in a good agreement (see Figure 7). The defined above value of an emissivity will be used a reference number for temperature measurements in accelerating cavities.

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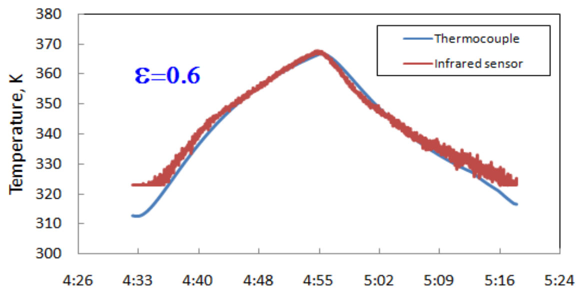

Figure 7: Comparing temperature measurements with infrared sensor at emissivity set of 0.6 relative to thermocouple data.

COUPLER OPERATION AT 7KW CW AT FULL REFLECTION

Figure 8 illustrates the 2D COMSOL model of the TTF-III coupler used for multiphysics simulations with 7 kW input RF power and full reflection. The temperature distribution has been calculated versus the. "Short" length L. Point of L=0 mm corresponds to the position of 2 K coupler flange. We assume in simulations that the Cu plating thickness on inner conductor is 100 µm.

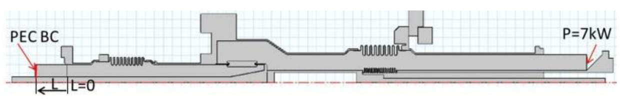

Figure 8: COMSOL 2D model for full reflection case.

Figure 9 and 10 shows the electric field distribution in the coaxial part of the LCLS-II power coupler and an electric field along the antenna body for on-resonance (no beam) and off-resonance operations. Figure 11 shows the temperature dependence versus the position of a reflection plane and temperature distributions along the surface of the inner conductor including minimum and maximum temperature values. The result for 7kW input power and TW regime is plotted for a comparison.

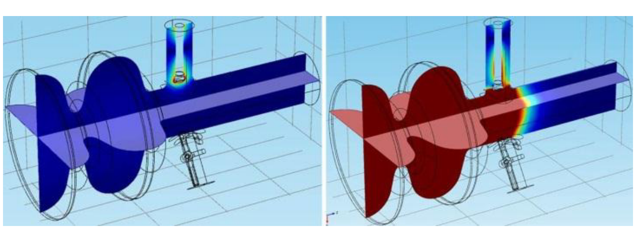

Figure 9: E-field distribution in LCLS-II coupler, Q=4e7, P=7kW. Off-resonance (left), on-resonance (right).

Simulations show that even in the worst case scenario the maximum temperature is below the limit of 450 K.

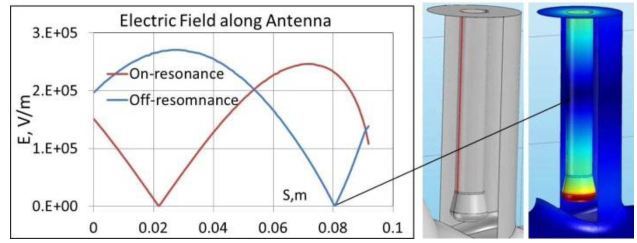

Figure 10: E-field (v/m) distribution along antenna. Field is plotted along red line on the antenna body.

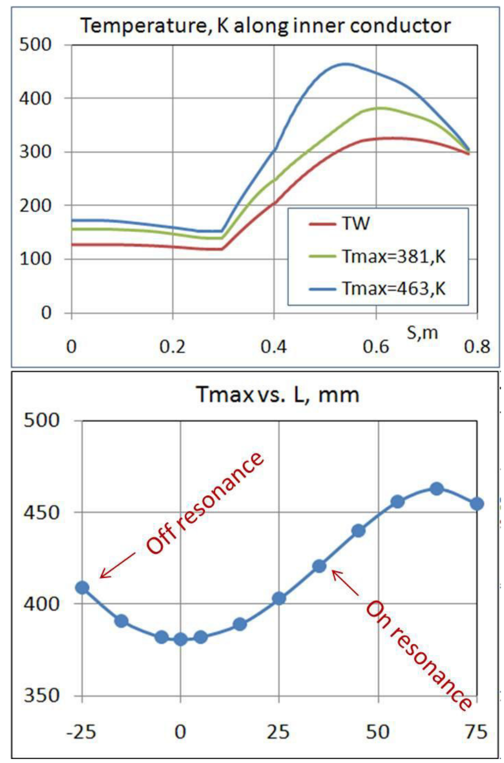

Figure 11: Maximum temperature vs. position of a reflected plane (down) and temperature distribution along the surface of the inner conductor (up).

CONCLUSION

Due to problems with Q_{ext} tuning range and overheating during CW operation the original TTF-III power coupler doesn't meet to the LCLS-II specifications. Two major modifications were proposed to overcome these issues: shorter antenna (by 8.5 mm) and thicker (>100 µm) Cu plating of the inner conductor in the coupler warm section. Ten original TTF-III couplers are planned to be reworked accordingly: re-plated at CPI and processed at SLAC soon. First two modified LCLS-II power couplers (two cold part and two warm sections) will be ready by the end of August 2014.

REFERENCE

[1] LCLS-II. Conceptual Design Report. SLAC-I-060-003-000-00. *SLAC-R-978*. SLAC National Accelerator Laboratory, Menlo Park, CA 94025.

[2] D. Kostin et al,"Status and operating experience of the TTF coupler, LINAC2004, MOP49.