# SIMULATIONS OF 3.9 GHz CW COUPLER FOR LCLS-II PROJECT*

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*Abstract*

LCLS-II linac is based on XFEL/ILC superconducting technology. Third harmonic cavity of 3.9 GHz is used to compensate nonlinear distortion of the beam longitudinal phase space. The TTF-III fundamental power coupler for the 3.9 GHz 9-cell cavities has been modified to satisfy to LCLS-II requirements and operation in the CW regime. In this paper we discuss the results of thermal analysis for proposed modifications of the power coupler design suitable for various operating regimes of the LCLS-II linac. The results of mechanical study are also presented

## INTRODUCTION

The LCLS-II SCRF linac consists of 35 1.3 GHz, 8-cavity Cryomodules (CM), and two 3.9 GHz, 8-cavity CMs. 3.9 GHz third harmonic superconducting cavities are used to increase the peak bunch current and to compensate non-linear distortions in the beam longitudinal phase space due to sinusoidal 1.3 GHz accelerating cavity voltage [1]. The fundamental power coupler (FPC) is an important and complicate component of the third harmonic system developed for the LCLS-II project. Table 1 shows main parameters of the 3.9 GHz cavity and cryomodule.

Table 1: Main 3.9 GHz CM and Cavity Parameters

| | Nominal | Min | Max |
|---|---|---|---|
| Average $Q_0$, 2K | $2.5x10^9$ | $2x10^9$ | |
| Average gradient | 13.4 MV/m | - | 15.5 MV/m |
| Nominal beam to RF phase | -150deg | -90deg | -180deg |
| Cavity R/Q | 750 Ω | - | - |
| G factor | 273 Ω | - | - |
| FPC $Q_{ext}$ | $2.5x10^7$ | - | - |

For a 300 uA beam current, a 15.5 MV/m accelerating gradient and a 180 deg beam-to-rf phase, the RF power induced by a beam and radiated to the power coupler is about 1700 W per cavity. If the cavity is detuned by 30 Hz due to microphonics ( nominally is 0 Hz detuning), the required input power to maintain the operating gradient would be about 80 W, so the coupler needs to be rated for at least 1.9 kW of average RF power (in particular, it needs to operate below the peak surface temperature noted below). Therefore in simulations we apply 2 kW of the input RF power in the TW regime.

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## POWER COUPLER DESIGN

Fermilab has developed a new 3.9 GHz power coupler for the third harmonic cavities for the TTF3 project after series of simulations and optimizations of different coupler designs [2]. The final design of the 3.9 GHz power coupler is shown in Fig. 1. It consists of a 50 Ohm coaxial line with a 30 mm diameter of the outer conductor.

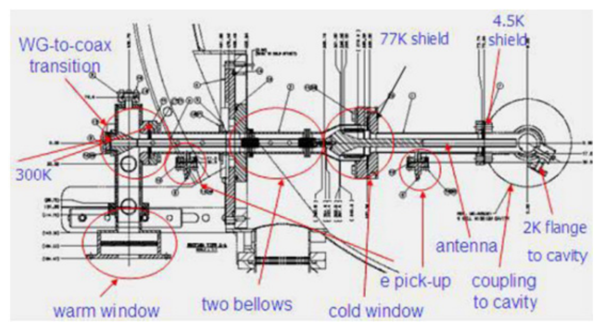


Figure 1: The 3.9 GHz power coupler developed at Fermilab.

Power coupler for the TTF3 project was designed for pulsed operation (Power is 50 kW, duration is ~2ms, repetition rate is 10 Hz). The LCLS-II requirements are CW operation at 2 kW in a traveling wave regime. At first, we performed COMSOL thermal simulations using LCLS-II parameters without any modifications of the 3.9 GHz TTF3 coupler. It is resulted in an overheating of the inner conductor of the warm part of the coupler up to 670 K. Thus, we propose the following modifications of the current design:

- Reducing the length of two inner bellows from 20 convolutions to 10 convolutions.
- Increasing the thickness of a copper plating in the inner conductor from 30 microns to 150 microns.
- Changing the antenna length to fulfil to the LCLS-II coupling requirement.

## THERMAL ANALYSIS

Thermally, the power coupler represents a connector from the room temperature (300K) to the superconducting cryogenic environment (2K). Figure 2 shows the thermal analysis model used in COMSOL simulations [3].

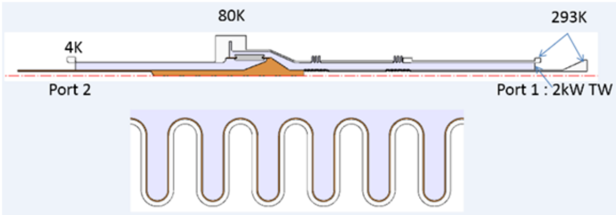

Figure 2: COMSOL thermal analysis model.

The traveling wave (TW) 2 kW input power is applied to the Port 1 with illustrated boundary conditions. We used copper thermal and electrical conductivity properties corresponding to RRR=50 taking into account anomalous skin effect [4]. Initial 3.9 GHz TTF3 power coupler has2 bellows with 20 convolutions on the inner conductor and 2 bellows with 3 convolutions on the outer conductor. Both conductors are made by a stainless steel coated with 30 microns of RRR=10 copper. The bottom illustration in Fig.2 shows the part of inner conductor solid model with copper coating layer. The temperature distribution in the original coupler design for the LCLS-II conditions (2 kW CW power in TW regime) is presented in Figure 3.

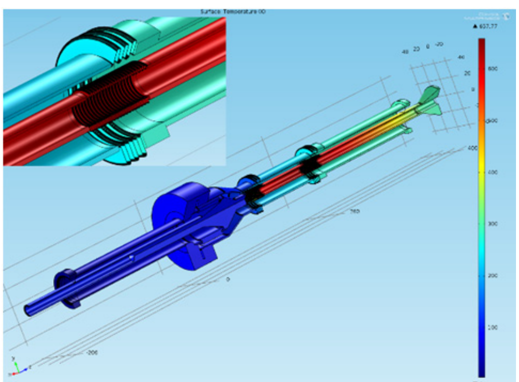
Figure 3: Temperature map in the TTF3 coupler with LCLS-II parameters. Max. Temperature is ~658 K.

As it is mentioned above, for solving the overheating problem we propose to reduce the length of two inner bellows from 20 to 10 convolutions and to increase the thickness of copper plating in the inner conductor from 30 microns to 150 microns. Figure 4 shows the results of both modifications which bring the maximum surface temperature down to acceptable value below 400 K.

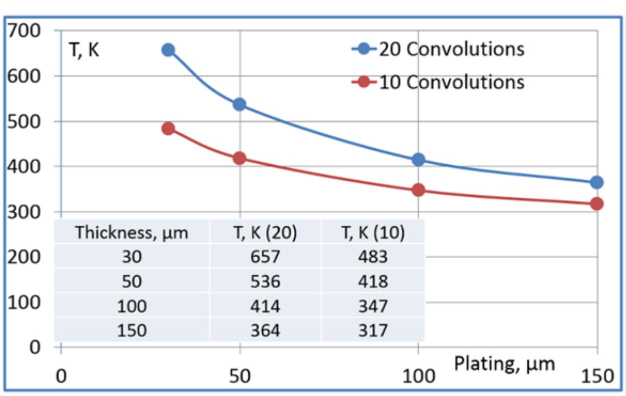

Figure 4: Maximum coupler surface temperature versus copper plating thickness and number of convolutions.

Finally we conclude that the optimal modification is a reduction of the convolution number to 10 and increasing the copper plating thickness of the inner conductor to 150 µm the maximum surface temperature in this case is 317 K (see Fig. 5). Static and dynamic parts of heat loads in the modified coupler are listed in the Table 2.

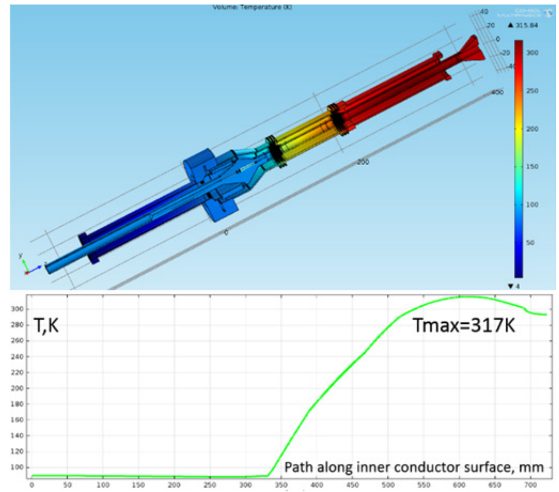

Figure 5: Temperature distribution along the coupler (up) and along the surface of the inner conductor (down) for modified coupler design.

Table 2: Dynamic and Static Heat Loads in the Modified 3.9 GHz Power Coupler

| | 4K | 80K |
|---|---|---|
| Dynamic, W | 2.1 | 5.9 |
| Static, W | 0.84 | 1.45 |

## MECHANICAL DESIGN

Analysis of mechanical stresses for original and modified couplers designs was performed by the COMSOL code. The coupler 3D solid model used in simulations is illustrated in Fig. 6. As a result transverse and longitudinal displacements of the coupler inner conductor have been evaluated. Coupler antenna is deformed in both transverse and longitudinal directions as it is shown in Fig. 6.

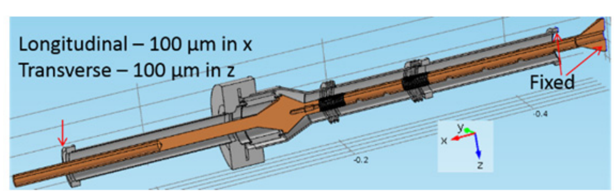

Figure 6: COMSOL solid model and mechanical boundary conditions.

Figures 7 and 8 show von Misses stresses for original and modified couplers for transverse and longitudinal deformations respectively.


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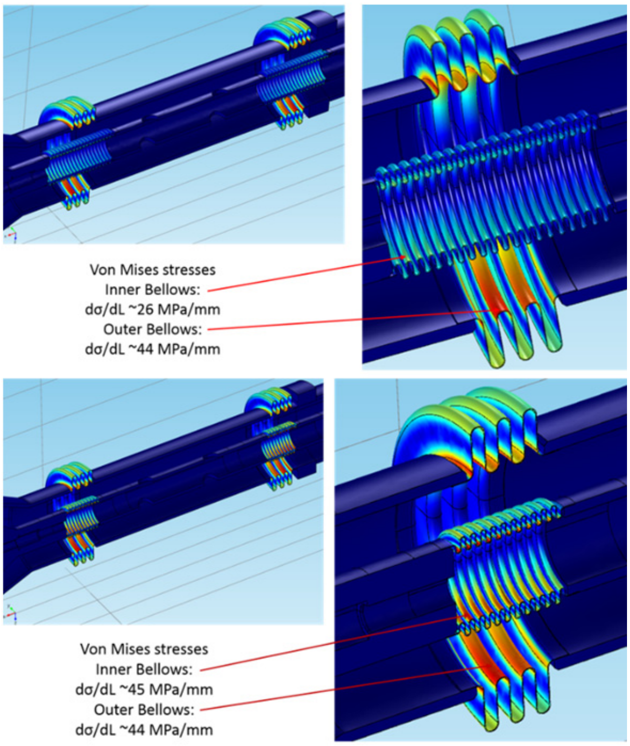


Figure 7: Von Misses stresses for original (upper) and modified (lower) couplers for transverse deformations.

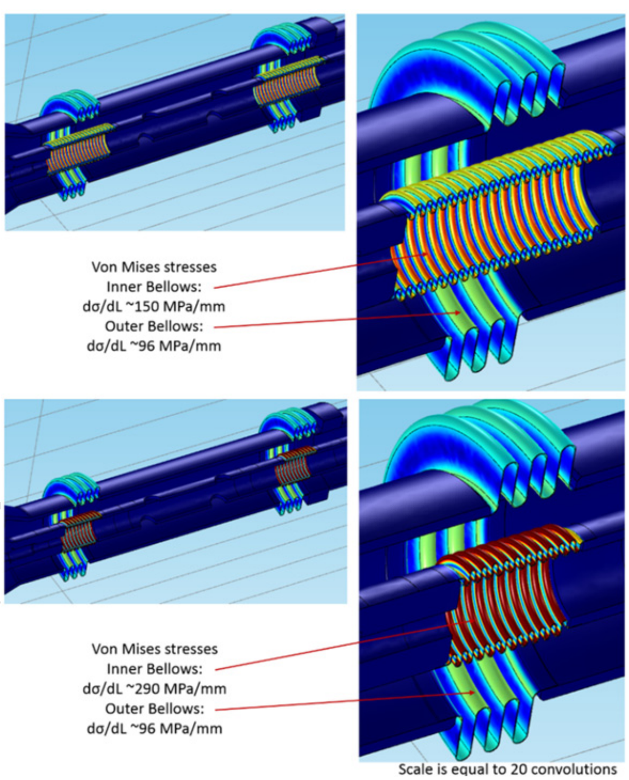


Figure 8: Von Misses stresses for original (upper) and modified (lower) couplers for longitudinal deformations.

Table 3: Summary of Stresses in Bellows

| | 20 convolutions | 10 convolutions |
|---|---|---|
| Inner conductor, transverse, MPa | 26 | 45 |
| Outer conductor, transverse, MPa | 44 | 44 |
| Inner conductor, longitudinal,MPa | 150 | 290 |
| Outer conductor, longitudinal,MPa | 96 | 96 |

The results of stress analysis are summarized in the Table 3. Simulations predict that expected deformation of bellows area during a cool down is about 1 mm, consequently the yield stress of bellows material can be as high as 290 MPa.

## ANTENNA REDESIGN

In order to fulfil to the LCLS-II requirements (see Table 1) and because the beam pipe diameter of the modified 3.9 GHz cavity is reduced from 40 mm to 38 mm the power coupler antenna position has to be matched again Fig. 9 shows simulated $Q_{ext}$ versus antenna penetration depth and Fig.10 shows the original and new tip positions corresponding to the external coupling of Qext =$2.5 \cdot 10^7$.

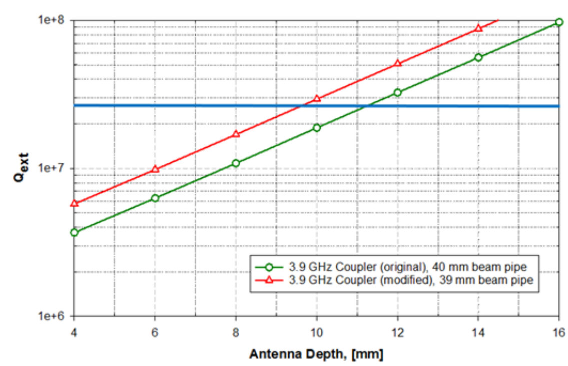


Figure 9: Coupler $Q_{ext}$ versus antenna depth.

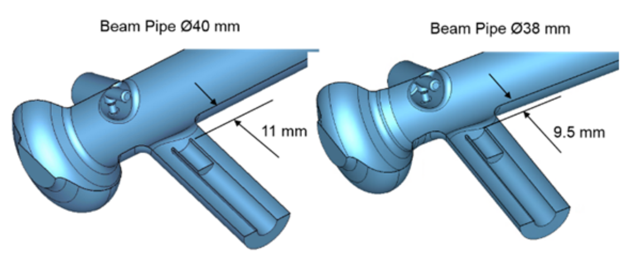


Figure 10: Antenna modification.

Figure 11 presents the results of beam loading simulations for different peak levels of microphonics.

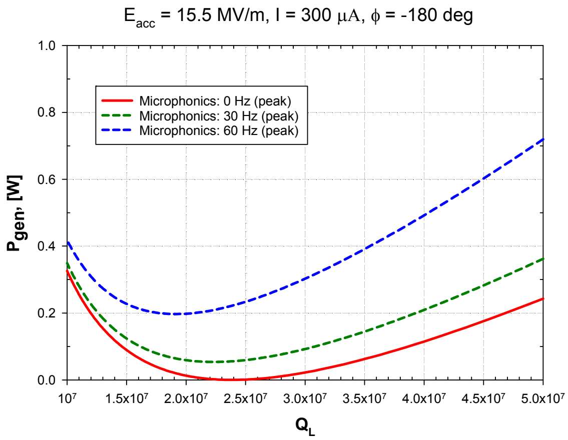


Figure 11: Input RF power required by the LCLS-II 3.9 GHz cavity with microphonics.

## MULTIPACTING ISSUES

Multipacting (MP) is a phenomenon of resonant electron multiplication which can be the reason of an electron avalanche and can abruptly absorb RF power and eventually lead to a breakdown. For a coaxial line, both one-point MP (from outer conductor to itself) and two-point MP from outer to inner conductor and back) may occur. In paper [3] we did detailed analysis of MP both cases in TTF3 power coupler based on the scaling lows.

For traveling wave found the threshold of MP is about 640kW, which is outside the range of our operating power levels.

## CONCLUSION

Modification of the TTF-III fundamental power coupler for the 3.9 GHz 9-cell cavity is proposed to satisfy to the requirements of the LCLS-II linac operation, The proposed modifications include a redesign of the coupler antenna, an increasing the copper plating thickness of the inner coaxial conductor and a reducing the number of the inner conductor bellows convolutions from 20 to 10.

## REFERENCES

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[2] Jianjian Li, et al “Simulations and Optimizations of a New Power Coupler for 3.9-GHz Supeconducting Cavities at Fermilab”, LINAC 2006, Knoxville, THP053; http://www.JACoW.org
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[4] http://cds.cern.ch/record/691905/files/project-note-2.pdf




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