MODIFIED TTF-3 COUPLERS FOR LCLS-II*

Chris Adolphsen#, Karen Fant, Zenghai Li, Christopher Nantista, Gennady Stupakov, Jeff Tice,
Faya Wang and Liling Xiao, SLAC, Menlo Park, CA 94025, USA
Ivan Gonin, Ken Premo and Nikolay Solyak, Fermilab, Batavia, IL 60510, USA

Abstract

The LCLS-II 4 GeV SCRF electron linac will use 280 TESLA-style cavities with TTF-3 power couplers that are modified for CW operation with input powers up to about 7 kW. The coupler modifications include shortening the antenna to achieve higher Q_{ext} and thickening the copper plating on the warm section inner conductor to lower the peak temperature. Another change is the use of a waveguide transition box that is machined out of a solid piece of aluminium, significantly reducing its cost and improving its fit to the warm coupler window section. This paper describes the changes, plating and surface issues, simulations and measurements of the coupler operation (heat loads and temperatures) and RF processing considerations.

INTRODUCTION

The LCLS-II project has adopted the TTF-3 coupler design (see Fig. 1) to power the 1.3 GHz TESLA-style cavities in its 4 GeV SCRF linac [1]. These couplers were designed for pulsed operation with several hundred kilowatts of input power at a ~ 1% duty factor, so the peak fields for 7 kW operation at LCLS-II will be much smaller. The low duty required the static heat load to be kept small, which was done by using only a thin (10-30 μm) layer of copper plating on the inner stainless steel surfaces. For LCLS-II CW operation, however, the inner conductor in the 'warm' section (between the windows) would overheat. Also the Q_{ext} range of the coupler is too low for the small LCLS-II beam currents (< 300 μA). Thus modifications were made as described below.

MODIFICATIONS

Thicker Copper Plating

Simulations show that with 7 kW fully reflected input power (worst case), the peak temperature of the warm inner conductor decreases from about 700 K to 400 K if its plating thickness is increased from 30 μm to 150 μm. This reduces the temperature below the 450 K level at which the couplers are baked so the vacuum levels should be manageable. LCLS-II adopted this thickness, which increases the 45 K total (static + dynamic) cryogenic load by 14 %. As a test, several ILC coupler warm sections were modified by removing their 30 μm plating and re-plating to 150 μm. The photo in Fig. 1 shows the achieved

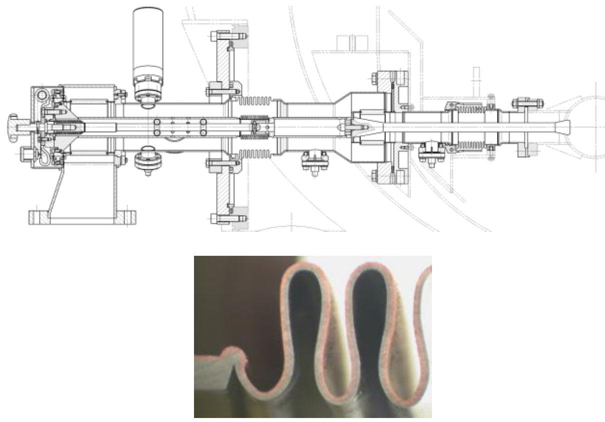

Figure 1: (top) TTF-3 coupler, (bottom) sectioned inner bellows after plating to 150 μm thickness.

plating uniformity in the bellows region, which meets requirements. So far these couplers have worked well and vendors are producing new ones with this plating thickness.

Shorter Antenna

The TTF-3 couplers can move over a 15 mm range, which changes Q_{ext} by about 19 % per mm. LCLS-II will run with $Q_{ext} = 4.1\times10^7$ (about 10 times higher than XFEL), which is above the nominal TTF-3 Q_{ext} range. To shift up the range, the flared antenna tip will be shortened by 8.5 mm, keeping the same flare angle and 3 mm radius edges. For the first two cryomodules, ILC cold sections have been modified by milling down the existing antenna tips using a fixture that prevents the couplers from being damaged.

Aluminium WG Box and Flex Rings

To lower cost and improve performance, the copper waveguide box that attaches to the warm window will be replaced by one machined from a single block of aluminium, without RF matching posts (see Fig. 2). Also the capacitor ring that allows HV holdoff will be replaced by a copper flex ring to provide a better RF seal between the waveguide and the coupler body.

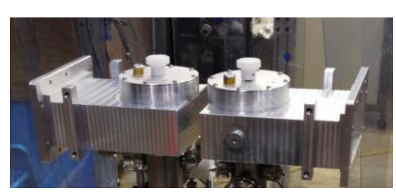

Figure 2: Pair of aluminium waveguide boxes being used for coupler RF processing.

*Work supported by the Department of Energy, Office of Science, Office of Basic Energy Science, under Contract No. DE-AC02-76SF00515
#star@slac.stanford.edu

SURFACE ISSUES

Surface Finish

After plating, the surfaces do not always look pristine as there can be loosely attached particles, blemishes and oxidation. Various methods are used by vendors to improve the surface appearance including brushing, Mo wool polishing and glass bead blasting. The concern is that this can imbed particles in the surface that may come loose later, and that it produces trapped volumes when protrusions are folded over. Figure 3 shows SEM photos of various 150 µm thick copper plated samples [2]. Our preference is for the plating to be done in a way that post processing is not required.

Roughness

Surface roughness can increase the RF losses if the height of surface features are a significant fraction of the spacing between them. For sinusoidal surface height variations,

$$y = h\cos(2\pi x/\lambda)$$

where the height (h) is much larger than the RF skin depth (worst case), Fig. 4 shows the RF loss enhancement for

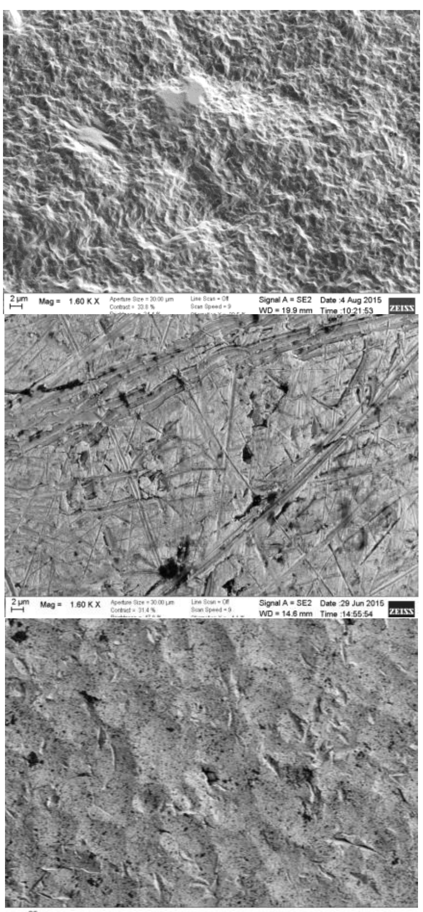

Figure 3: SEM photos of 150 µm thick copper plating: (top) bellow with no post processing, (middle) Mo wool polished bellow and (bottom) bead blasted coupon.

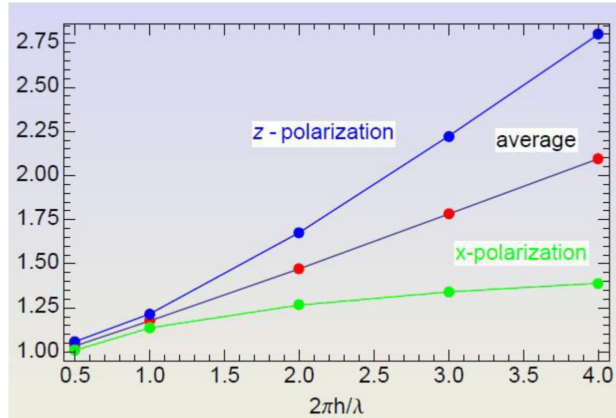

Figure 4: RF loss enhancement for sinusoidal surface variations with two H field polarizations.

two polarizations of the H field: (z) with the field parallel to the sinusoidal ridges and (x) perpendicular to them. Most plated surfaces have features for which $2\pi h/\lambda < 0.5$ so the enchantment should be less than 10 %.

Oxidation

Despite the use of best handling practices, oxidization of the copper sometimes occurs at various stages before assembly and after processing. Our attempts to reproduce it have had limited success, and no study has been done to determine the oxidation thickness and composition. Conversely, it has not been seen to adversely affect RF operation at various labs. Thus the general approach has been to live with it if it occurred using normal procedures. Figure 5 shows a particularly bad oxidization example.

SIMULATIONS AND MEASUREMENTS

Temperatures and Heat Loads

The heat loads from the couplers are a sizeable fraction of the SCRF linac cryoload, and extensive 2D and 3D simulations are being done at SLAC and FNAL to estimate their size. Also, the coupler loads in single cavity (HTS) tests are being measured to verify the estimates, which may be inaccurate due to uncertainties in the copper RRR, ceramic window loss tangent, roughness effect on resistivity (see above) and thermal anchoring

Figure 5: Example of copper oxidation.

ISBN 978-3-95450-178-6

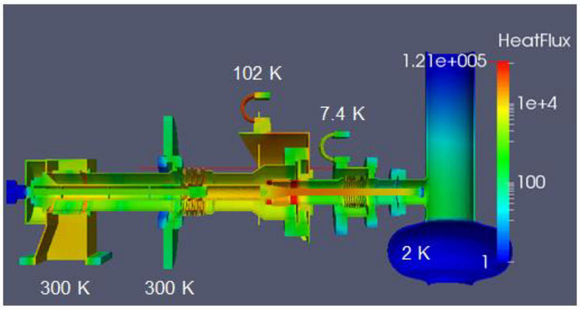

Figure 6: Simulation of the coupler heat flow given the measured/expected thermal intercept temperatures that are shown. The color map is of the heat flux (W/m^2).

effectiveness. As an example of the simulations, a map of the coupler heat flux (in W/m^2) is shown in Fig. 6 for 3.7 kW input power that is fully reflected from an on-resonance cavity (roughly the maximum LCLS-II operation equivalent). The total heat load (static plus dynamic) going to the 2, 5 and 80 K thermal intercepts are computed to be 0.12, 0.9 and 17 W, respectively. The maximum temperature, which occurs on the bellows of the inner 'warm' conductor, is 326 K.

Effect on the 2 K Dynamic Load

Since the heat deposited at 2 K takes the most energy to remove, it is important that the coupler induced 2 K load be small. Figure 7 shows that the measured Q_o of a cavity at 15 MV/m was basically unaffected by the coupler power level, as expected. This measurement was done at Cornell where the coupler flanges were cooled with He gas lines [3].

RF Processing

The input power is generally below the coupler multipacting threshold so it is not clear that RF processing does much other than to 'bake' the coupler in-situ due to the RF heating. For example, Fig. 8 shows that the vacuum levels are unaffected by large variations in the 30 kW input power at low duty (~ 0.5%) during TW operation of a pair of couplers.

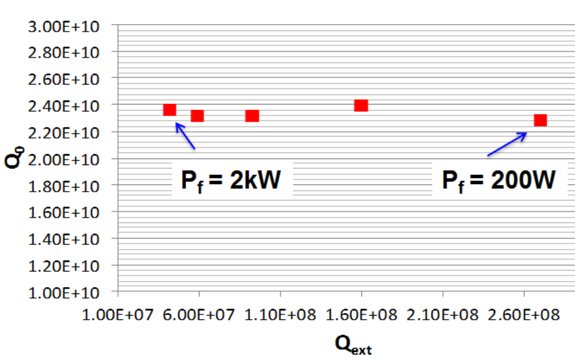

Figure 7: Measurements of the Q_o of a cavity at 15 MV/m at various input power levels (P_f) achieved by changing the cavity external quality factor (Q_{ext}) using the coupler antenna adjustment feature.

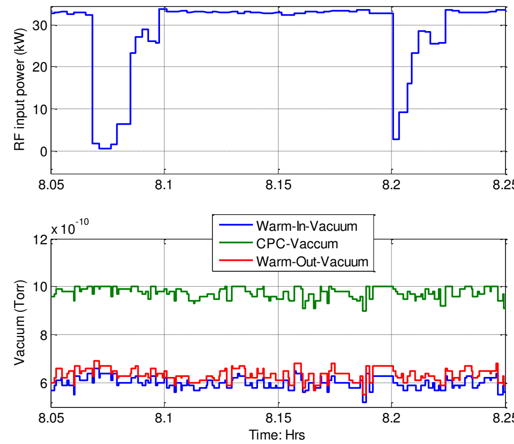

Figure 8: Data taken during RF processing of a pair of couplers with 30 kW pulses of 1 msec at 5 Hz. The top plot shows the power and the bottom plot the vacuum levels in the three coupler volumes (two warm sections and common cold section with connecting waveguide).

CONCLUSION

For LCLS-II, the TTF-3 coupler design has been modified for CW operation where beam currents up to 300 µA are accelerated at 16 MV/m. The copper waveguide box has also been replaced with a lower cost, more robust design made of aluminium. The main outstanding task is to verify that the heat loads associated with the couplers agree reasonably well with expectations so that, in particular, the 5 K cryoload does not exceed the cryoplant capacity.

REFERENCES

[1] LCLS-II Final Design Report Draft, LCLSII-1.1-DR-0251-R0, SLAC, Dec, 2014.
[2] SEM photos courtesy of Chris Pearson, SLAC
[3] Ralf Eichhorn, Dan Gonnella and Matthias Liepe, Cornell University, March, 2015, *http://slacspace.slac.stanford.edu/sites/lcls/lcls-2/cryogenic/cryomeet/150318Cornell_high_Q0.pptx*