SLAC/FNAL TTF3 COUPLER ASSEMBLY AND PROCESSING EXPERIENCE*

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Abstract

The TTF3-style coupler is typically used to power 1.3 GHz TESLA-type superconducting cavities. For the US ILC program, parts purchased in industry for such couplers are received at SLAC where they are inspected, cleaned, assembled as pairs in a Class 10 cleanroom, pumped down, baked at 150 °C and rf processed. The pairs are then shipped to FNAL and installed in cavities that are tested at input power levels up to 300 kW. This paper describes the coupler results to date, including improvements to the preparation procedures and efforts to understand problems that have been encountered.

INTRODUCTION

The International Linear Collider (ILC) will contain about 16,000 superconducting cavities. Each cavity will have a power coupler that transports ~ 300 kW, 1.6 ms, 1.3 GHz rf pulses at 5 Hz from a waveguide feed at room temperature through a coaxial line to an antenna that protrudes into the 2 K cavity beam pipe. Fig. 1 shows the TTF3 coupler design [1], which was developed by the TESLA Collaboration and is being used for ILC cavity R&D in Europe and the US and for the European XFEL project. The design is complex due to requirements on thermal expansion, heat load, vacuum, Qext adjustability and high voltage isolation. In particular, four thin bellows are used to allow flexibility and adjustability, the inner stainless surfaces are plated with a thin copper layer to reduce rf losses while limiting heat loss and the windows are TiN coated to suppress multipacting.

The cryomodule program for the US ILC effort is centered at FNAL, and SLAC is providing TTF3 couplers for the cavities that are being 'dressed' there. So far, all couplers have been purchased from one vendor. They were fabricated using brazing and e-beam welding techniques, and then shipped to SLAC where they were inspected, cleaned, assembled in a Class 10 room, pumped down, baked at 150 °C and then rf processed [2]. The first couplers were rf processed in 6/09, and this paper discusses the progress and the lessons learned since then.

PROCESSING HISTORY

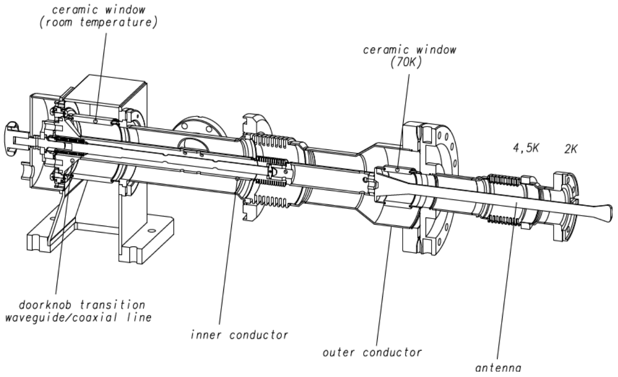

Figure 1: TTF3 L-Band Power Coupler.

To date, 18 couplers have been inspected, assembled and rf processed at SLAC, and shipped to FNAL where 16 have been installed in cavities that have been tested in their Horizontal Test Stand (HTS). At SLAC, the couplers are rf processed at room temperature in pairs using a specially designed disk-shaped cavity to couple the power between the pairs via their antennas. For this processing, the input power is slowly increased up to 1.3 MW, paced by the outgassing level (limited to 10^{-6} Torr), at progressively longer pulses (20, 50, 100, 200, 400, 800 and 1050 µs). At 800 us and 1050 µs, the power is kept below 650 kW to limit average heating, although for the most recent pair, the repetition rate was lowered to 1 Hz for the 1050 µs operation and the power ramped to 1.3 MW to better match the long pulse SW operation at FNAL.

The integrated periods of power-ramping were typically 10-20 hours for the nine pairs, although they were operated up to 50 hours including fixed power periods to verify that the monitored signals (vacuum, light in the air-filled waveguide and electron probes in the coupler vacuum) continue to decrease over time. The electron probe signals, which are monitored using an electronics module designed at FNAL [3], indicate strong multipacting during the initial power ramp-up, which is to be expected. This activity tapers off during processing as the surface gas layer is removed. No rf breakdown has been observed at the high power levels, which is not surprising given the low surface fields.

At FNAL, the couplers need to be rf processed again after installations on the cavity (cold section) and in the HTS (warm section), as the inner surfaces are exposed to air. This is first done at room temperature where the rf power is fully reflected. A similar conditioning protocol as that described above is used, except that the power is limited to 280 kW, the maximum pulse length is 1.3 ms and all operation is at 2 Hz. It usually takes 25-40 hours to complete the processing. The factor that most limits the conditioning time is the intense degassing in the warm part of the coupler, which causes vacuum spikes above the interlock value.

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After the cavity is cooled to 2 K in the HTS, rf conditioning is done on-resonance. In order to mimic the gradient flat top during beam operation, the input power is decreased by a factor of four after the nominal cavity fill time (500 µs), after which nearly full reflection occurs. During the initial cold conditioning, the input power is limited to 230 kW, which corresponds to a 25 MV/m cavity gradient. The power is then manually increased until either the cavity quenches or 35 MV/m is reached.

For two of the early cavities, the performance was clearly limited by the cold coupler sections. Both of these sections had been returned to the vendor for repair. In one case (see the left-most photo in Fig. 2), a few mm strip of plated copper had come off near the flange that attaches to the cavity and was vaporized by the rf (see the lighter color copper 'spray'). The vendor had been asked to remove excess copper plating just outside of the region where the copper came loose, as the plating had extended into the flat region where an aluminum gasket is used to vacuum seal the coupler to the cavity. Apparently this removal weakened the copper plating in the rounded region as well, and a strip came off during high gradient processing.

The other failure (see the right-most photo in Fig. 2) is more puzzling. In this case, the copper in the rounded region was smoothly eroded around the entire circumference, leaving several patches where the underlying stainless steel can be seen. When the cold section was removed from the cavity at FNAL, copper flakes were observed on the antenna. One guess is that this region heavily multipactored due to contamination of the copper in this area. Although the vendor had made a repair in the window region of this section, they had also bead blasted the plated surface, which gives it a cleaner appearance (this will be discussed more below – note that this was not done to the other failed coupler). Before bead blasting, they had masked off the region where the copper eventually eroded (since it is near the surface that provides the vacuum seal), and perhaps the masking material introduced contaminants (one can see a clear demarcation between the bead blasted surface and the eroded area in the photo). Nothing like this has been observed again.

INSPECTION IMPROVEMENTS

Although these failures may be unique, efforts have been made to improve the coupler inspection process when they are first received to better capture any imperfections. A full borescope video inspection of the coupler inside surface area is now made using an Everest VIT borescope. Prior inspection images were taken only of non-conforming parts. For these video recordings, a full rotation of the coupler is made with the borescope located at a fixed longitudinal position. The coupler is then moved by ½ inch with a linear stage, and the process repeated until the full interior has been examined. These data are stored on the metrology report website if needed for future review, in particular, if a coupler is found to have problems during operation (although for the two failed couplers, the images that had been recorded did not give any indication of a problem).

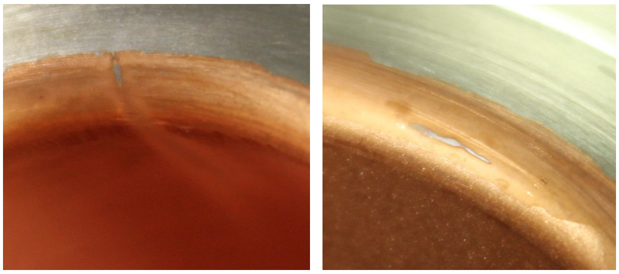

Figure 2: Copper removal observed near the output flange in two coupler cold sections after rf operation at FNAL.

Another change introduced is to 'exercise' the cold coupler bellows before the borescope inspection. The couplers are installed on a vertical stand that has ± 5 mm limit stops, and they are compressed/expanded ten times over this range. A Class 100 cleanroom wipe is placed under the vertical stand to see if any copper particles come off during actuation, which has not occurred thus far.

COPPER PLATING ISSUES

Given the issues with two of the couplers noted above, all aspects of the copper plating were reviewed. In particular, the effect of ultrasonic cleaning on particle generation was examined. This study was also motivated by the change in the post-plating treatment of the copper by the vendor. Instead of using a brushing process to remove general discoloration, which leaves scratches, bead blasting was used to clean the entire surface. For the study, the vendor and SLAC produced flat test coupons to mimic the coupler copper plated inner stainless steel surfaces (cyanide copper process, 10 µm thick). Each coupon was dimensionally the same (2" square with a ¼" hole in one corner). The vendor supplied 10 bead blasted and 9 non-bead blasted coupons and SLAC supplied 8 non-bead-blasted coupons (4 with 10 µm plating, and 4 with 30 µm plating, which is the thickness on the warm section center conductor).

Figure 3 show SEM photos of the surface for the three types of copper finish before ultrasonic cleaning. The vendor non-bead blasted surface is much rougher than that resulting from the SLAC plating process. This is likely the result of SLAC doing a periodic-reverse polarity change during the plating (25 seconds 'forward' plating followed by 5 seconds of 'reverse' plating), which the vendor does not do. The vendor bead blasted surfaces are smoother, but crevasses and sharp edges are produced. Inspection after ultrasonic cleaning did not show significant difference, which suggests that the ultrasonic cavitations are not so strong as to appreciably transform the surface.

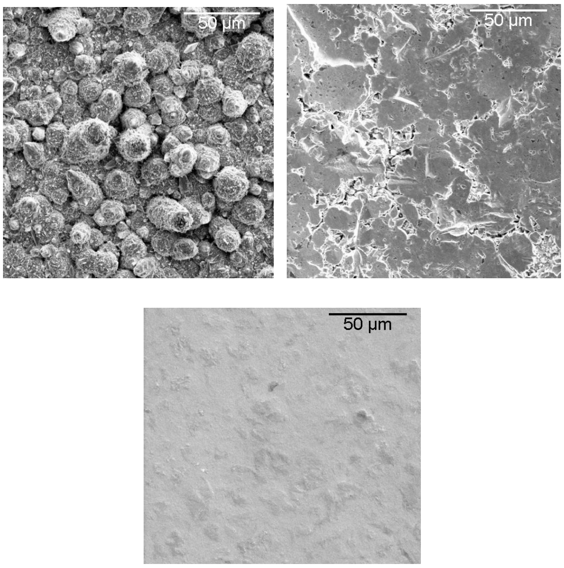

Figure 3: SEM photos of the copper coupon plating: (top left) vendor non-bead blasted, (top right) vendor bead blasted and (bottom) SLAC non-bead blasted.

To test the coupons for flaking, each one was ultrasonically cleaned three times for 15 minutes at the nominal transducer power setting of 1.6 kW, 40 kHz, with no frequency sweep. Eight coupons were processed at a time, and each was suspended in a pre-cleaned glass container using a stainless steel wire. Ultrapure water was filled within 6 mm of the brim in the glass containers and in the outside tank. Before coupon cleaning, power levels were measured with a PB-500 Megasonic Ultrasonic Energy Meter/Probe and ranged from 8 to 30 W/inch^2 in the eight glass containers.

Filter sampling was done after each ultrasonic bath and after a rinse cycle following the first bath (thus, four samples were taken per coupon). The bath water was poured through a 47 mm diameter Millipore hydrophilic membrane that captures particles greater than 0.45 µm. A one square mm region was photographed with a VZM-200 Digital Video Measurement System and rendered into a 3D image based on surface brightness. Copper particles appear as peaks, and a software application was used to determine their sizes. The particles were counted by hand and grouped in three categories: greater than 25 µm, 10-25 µm and less than 10 µm. The count was limited to 50 in each category.

Table 1 lists the particle counts averaged over both the three ultrasonic baths and the coupons of a given type. For these averages, a count greater than 50 is entered as 50 so the average cannot exceed this value. The results show the vendor bead blasted coupons have the highest count as may be expected given that the surface 'nodules' are flattened by the beads. The vendor non-bead blasted values are somewhat smaller, and the SLAC non-bead blasted values are at least an order of magnitude smaller, consistent with the smoother surface. Interestingly, the particle counts in all cases did not necessarily decrease with repeated ultrasonic cleaning, which may mean the ultrasonic power level is too high for this soft copper.

OUTLOOK

Although the vendor plating with or without bead blasting produces copious copper flakes during ultrasonic cleaning, subsequent water rinses do not show further copper removal. Also, after rf processing one of the coupler pairs, the two cold ends were removed from the test set-up in the Class 10 cleanroom at SLAC. A visual inspection and a filtered nitrogen blow-out with a particle counter showed no indication that particles had been generated during the 50 hours of rf operation. In the future, a filtered rinse sample will be taken from a cold section that has been installed and operated in the FNAL HTS to look for particles.

The fact that five recent cavities with bead-blasted couplers achieved gradients greater than 33 MV/m at FNAL suggests that the plating is not a major issue, although some of the cavities showed X-ray bursts. Nonetheless, the vendor should improve the plating process for future couplers to further reduce the possibility of cavity contamination.

Table 1: Coupon particle count results.

Coupon Sample	Avg. # Particles > 25 µm per mm^2	Avg. # Particles 10-25 µm per mm^2	Avg. # Particles < 10 µm per mm^2
Vendor Bead Blasted	12	40	47
Vendor Non-Bead Blasted	3.2	14	30
SLAC 30 µm Plating	0.55	2.3	3.0
SLAC 10 µm Plating	0.46	1.8	2.6

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REFERENCES

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[2] C. Adolphsen, *et al*., 'Coupler Development and Processing Facility at SLAC,' WE5PFP019, PAC09, Vancouver, BC, Canada, May 2009.

[3] Peter Prieto, private communication.