STATUS AND LESSON LEARNED FROM MANUFACTURING OF FPC COUPLERS FOR THE XFEL PROGRAM

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Abstract

For the XFEL accelerator, Thales, RI research Instrument GmbH and LAL are working on the manufacturing, assembly and conditioning of Fundamental power couplers (FPC), 670 couplers have been manufactured. The main characteristics of these couplers are remained at 1.3 GHz.

The paper describes the full production activity from the starting of the program, lessons learned from a mass production and different steps necessaries for obtaining a rate up to 10 couplers a week.

We propose also some other way to be optimized for a future possible mass production of such components. With comparison of processes and adaptation which could benefit to an increase rate, if needed, including some of them which could be studies from the coupler definition to the manufacturing process in order to obtain a stable and possible increased rate or lower cost of production by decreasing the risks on programs.

INTRODUCTION

Fundamental coupler main parameters are [1]:

- RF frequency: 1.3 GHz
- Peak Power: 150 kW
- Pulse length: 1.3 ms
- Repetition rate 10 Hz
- Tuning : ± 10 mm
- Coupling (Qext) $2x10^{6} \rightarrow 2x10^{7}$
- Two ceramics windows

The main metallic sub-assemblies of a coupler are the Warm External Conductor (WEC), Warm Internal Conductor (WIC), The Cold External conductor (CEC) and the antenna, see Fig. 1.

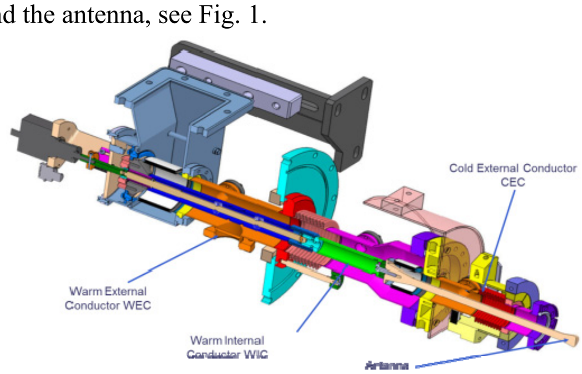

Figure 1: Coupler general layout.

COUPLER MANUFACTURING

Main steps in the coupler fabrication, already described [2], consist in parts assemblies, copper coating of RF surfaces, TiN coating of ceramics windows then all parts are EB welded and clean in an ISO 4 room before being sent to LAL for RF conditioning at 1 MW peak before assembly on cryomodule at IRFU.

Thales Production

The XFEL couplers sub-assemblies are based on a brazing technology. This technology allows having a better reproducibility than a welded one, which is more operator dependant and also could be performed by batches, which is useful for a mass production.

Once the sub-assemblies are brazed and prepared, the three main one (WEC, WIC and CEC) are copper coated, as illustrated in Fig. 2.

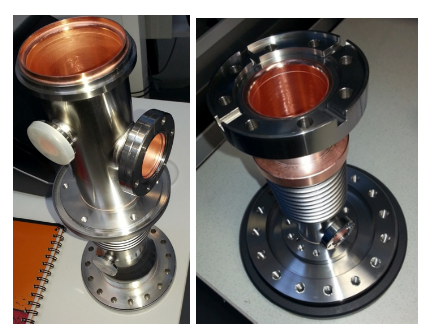

Figure 2: Warm and Cold External conductor.

Thickness and tolerances on WEC and CEC are of 10 µm ±20 % on tubular parts and ± 30% on bellows, For WIC thickness is of 30 µm ±20 % on tubular parts and ±30% on bellows. RRR value initial specification was from 30 to 80.

For copper coating acceptance on visual criteria a special document have been establish on order to have common and objective criteria [3].

This document defines the tooling for control and objective criteria on what is acceptable and what is not acceptable. These criteria are illustrated by pictures giving examples of parts of pieces with real cases observed during inspection of subassemblies.

This is a major document for common understanding on acceptance of pieces during the program. This document is of particular interest for the gap existing between perfect pieces and enough good ones to be used.

During the overall manufacturing of couplers, parameters are always controlled and samples are used to verify continously the reproductibility of results.

RRR value and thickness measurements on real part of couplers are regularly done to check that the process results remain constants, with these values strong statistics have been obtained on dispersion, example of such measurements are given on Fig. 3, and 4 with the place where measurements are obtained for the three main sub assemblies.

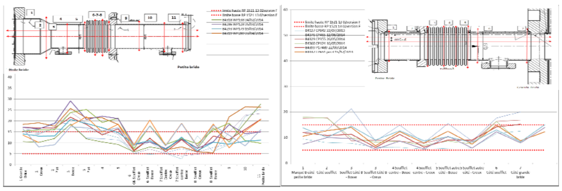

Figure 3: WEC, CEC thickness measurements example.

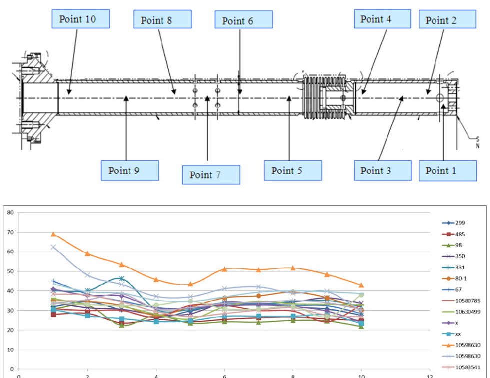

Figure 4: WIC thickness measurement example.

RI Production

At RI factory, the ceramics windows are prepared with a TiN coating of 10 nm nominally; the subassemblies received are double checked in quality in order to identify eventually defects. Fig. 5.

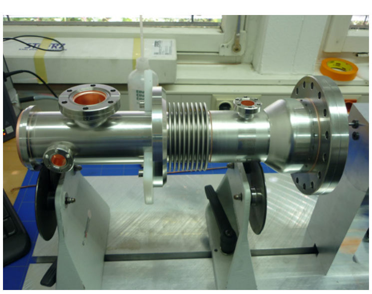

Figure 5: tooling for quality inspection at R.I.

Once the sub-assemblies from Thales are received at RI factory, the integration of warm and cold part is done by EB welding of CEC, antenna and cold ceramic for the Cold Part and WEC, WIC and ceramic for the Warm Part. Then assembly and cleaning is done according to the procedure defines by LAL [1]:

Then the coupler pair is double bagged and placed in a special shipping box and send to LAL.

LAL Process

Once received at LAL, an in-situ baking cycle is carried on in order to remove residual water vapour [4].

This baking cycle under vacuum is typically of 75 h at 150°C [5].

Treatment of 12 couplers in the same time is allowed thanks to the 3 ovens equipping the clean room.

Antenna tuning is performed before the coupler pair is installed in the RF test bench for conditioning.

An automatic test bench with a RF power source of 5 MW peak has been jointly developed and installed by Thales and LAL [6] allow conditioning of 4 coupler pairs in parallel.

Automatic procedure consists on a gradual ramp of RF up to 1 MW at 400 µs followed by a 500 kW sequence at 1.3 ms [4].

A 5 coupler pairs per week capability have been demonstrated.

Overview on Coupler Production

After a long ramp up of the program where manufacturing tools and processes have been developed, a capability of 10 couplers manufacturing per week have been demonstrated over months. This capability has been demonstrated by Thales, RI and LAL.

Figure 6 represents the production chart from sub-assemblies to delivery for cryomodule integration at Saclay. The ramp down of such program must also be considered as a lot of couplers subassemblies related to some couplers rejected during the full production activity have to be repair and reassembled.

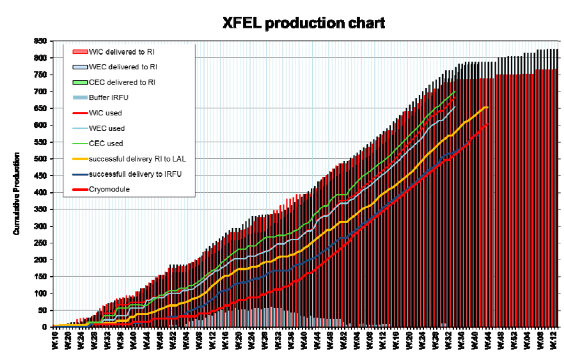

Figure 6: Overall production chart.

Lesson Learned and Possible Way for Optimizing FPC Production

Manufacturing improvements and possible ways to increase rate of production could be considered [3], [7].

We learned during the production of such couplers that final parameters still have significant dispersion on measurement. As an example RRR value have been observed with a significant and unexplained dispersion, see Fig. 7 and Fig. 8.

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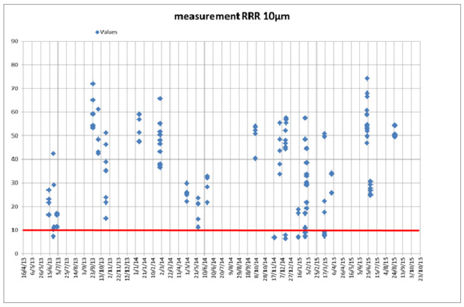

Figure 7: RRR dispersion on copper at 10 µm.

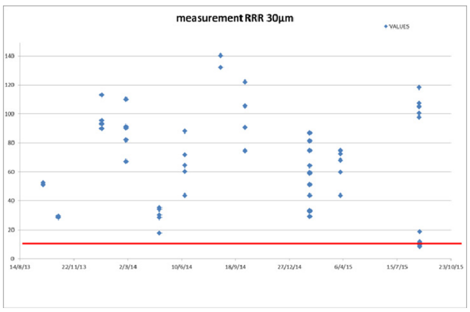

Figure 8: RRR dispersion on copper coating at 30 µm.

Some other unexplained phenomena have been also observed [7]. After conditioning of couplers some dark shadows, Fig.9, may appear on ceramics, these shadows were not observed before conditioning and present a little influence on vacuum while conditioning but without any significant impact on the RF processing.

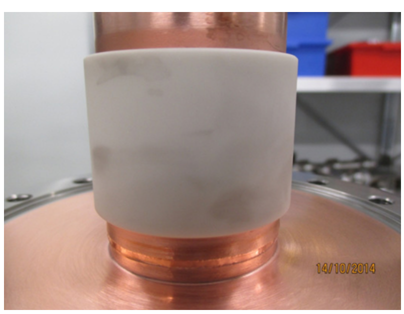

Figure 9: Tinted ceramic after RF conditioning.

Some possible ways could be envisaged for improving manufacturing and acceptance of a FPC mass production among them:

- Studies on remaining parameters which could influence dispersion or their measurements.
- Studies for avoiding processes remaining which are operator dependant and which could be replace by automatic sequences.

Avoiding processes which are operator dependant allow also being in a position of manufacturing sub-assemblies by batches in furnaces increasing then the rate of production.

CONCLUSION

XFEL coupler production of up to 10 conditioned couplers per week has been demonstrated. Important phases on such program are ramp up and ramp down.

It is also important to consider acceptance criteria which are commonly share between participants this include visual acceptance criteria which must be strictly define.

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