MANUFACTURING OF THE IFMIF SERIES POWER COUPLERS

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Abstract

In the framework of the International Fusion Materials Irradiation Facility (IFMIF), which consists of two high power CW accelerator drivers, each delivering a 125 mA deuteron beam at 40 MeV, a Linear IFMIF Prototype Accelerator (LIPAc) is presently under construction for the first phase of the project. Eight power couplers are needed for the cryomodule of LIPAc. After the validation of the two prototypes, the manufacturing of the Series Power Couplers was lunched. This paper will report the status of the manufacturing progress. It will also describe the acceptance tests in addition to the criteria adopted for these critical RF power units. The manufacturing imperfections and some finishing techniques used for the different parts will be also presented and discussed.

IFMIF POWER COUPLER LAYOUT

The IFMIF Power Coupler (PC) has a 50 Ω coaxial geometry and consists of three main parts (Fig.1): RF Window, “T” Transition and Cooled Outer Conductor (COC). Except the “T” transition outer conductor, made of aluminium, all the RF surfaces are bulk or coated OFHC copper. An active GHe cooling system is used to interface the SC cavity with the room temperature (RT). More details on the PC are presented in [1].

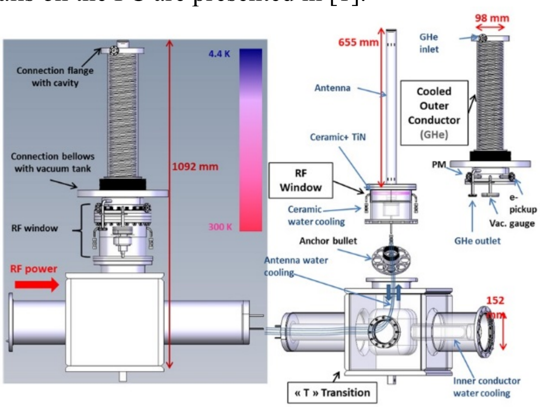

Figure 1: IFMIF Power Coupler Layout.

STATUS OF THE IFMIF SERIES PCS

The manufacturing of the first PC pair was completed. Factory acceptance tests were performed, then, the shipment to CEA was carried out on April 2016.

The remaining units are progressing through the production line. The second PC pair is well advanced: One COC is already successfully plated, and the next unit will be plated in the next couple of days. Both of the Window Assemblies are complete and are being prepared for the TiN coating. The “T” Transition Assemblies have been welded, and are ready for final cleaning. For the next pairs, most of the subassemblies of the couplers are complete.

Each coupler pair shipped to CEA will be inspected and undergo additional leak tests. Appropriate tools will be assembled on couplers to protect them during handling and transport operations. Afterwards, vacuum PC parts will be cleaned in ultrasonic (US) bath with detergent and assembled in ISO5 cleanroom. The cleaning procedure is the same as for the prototypes [2]. The PCs will be transferred to CIEMAT for their RF conditioning @ RT. The integration of the PC into the LIPAc Cryomodule will be accomplished in Japan.

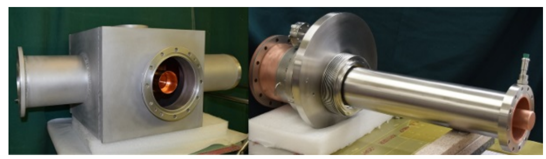

Figure 2: IFMIF Series PC (first unit).

ACCEPTANCE TESTS AND CRITERIA

The major part of the acceptance criteria are quantitative and are based on precise predetermined requirement and measurements results. For some aspects based on visual inspections, the acceptance can be based on “qualitative” criteria along with the specifications. Generally, using very strict criteria can have dramatic consequences on the rejection rate of the manufactured parts. However, tolerating certain minor defaults needs an estimation of their impact on the PC behaviour. Decisions are generally based on the nature of the encountered anomalies, the analysis and the experience exchanges between the PCs users and manufacturers.

Quantitative Acceptance Criteria

Acceptance of the coupler parts The COC has experimented series of mechanical stress tests before being leak checked. It was initially thermally shocked with LN2 and warmed again 5 times. Afterward, the helium circuit of these parts was pressurised up to 6 bars, while its nominal operating pressure is less than 1.5 bar.

Concerning the water circuits (Fig. 1), flow test was performed where the pressure drop was measured with the nominal flow rate and compared to the expected value. A hydrostatic pressure test was also run using water coolant on each flow channel to qualify the pressure capability and to check for leaks. The coolant flow channel was operated at twice the pressure experienced during the flow tests. Acceptance is based on having no leak during the test, while holding hydrostatic pressure throughout the test.

Assembly and disassembly tests was also performed on parts on the contractor premises in order to solve all interface issues before delivery.

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All the vacuum parts was leak checked and showed a tightness below 10^{-11} Pa.m^3/s. The final test was a global leak test with all the vacuum parts assembled together with the final tightness hardware.

The brazing cycles, thermal shocks, vacuum pumping and handling can have an impact on the bellows and generate small deformation of one or two waves. For that reason the displacement requirements to be guaranteed by the bellows during the PC operations are also checked.

The dimensional control was performed using a Coordinate Measurement Machine. The most critical dimensions concern the axes concentricity of the antenna tip comparing to the coupler cavity flange and the extension of the antenna beyond this same flange. These two dimensions have a direct impact on the Coupler Q_{ext} with HWR cavity and its RF matching with the RF conditioning test box. The measurements obtained on the first pair were acceptable.

Acceptance of the copper plating process The first acceptance test concerns the copper plating procedure especially for the COC which needs to have a specific thickness and RRR value. The qualification was performed in the same way as for the prototype couplers, see [1]. The thickness and adhesion was checked on a cylindrical copper plated sample having the same diameter than the coupler COC. The thickness measurements by optical microscopy (Fig. 3) and X-RAY XDL instrument was between 20µm and 30µm, as specified. The RRR was measured on rectangular sample copper plated and heat treated at 400°C, in the same way as expected for the PC. The results was RRR= 32. Specification was 20<RRR<80.

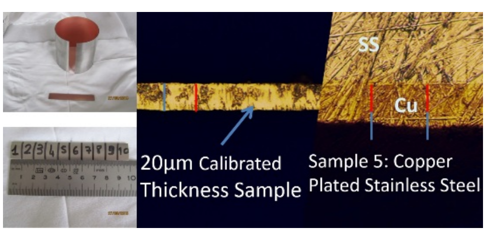

Figure 3: Copper plating thickness measurements.

The cleanliness and aspect uniformity on samples was also acceptable. Nevertheless, it is usually more problematic to obtain such a good result on final parts because they have more complex geometry, larger plated surface and also different life cycle which increase the handling operation and the risks of damaging. The visual inspection on final parts is mandatory to estimate the final quality of the copper plating. This inspection is generally subject to qualitative criteria.

Qualitative Criteria: Visual Inspection

The visual inspection is a crucial validation phase during the qualification of the couplers. It allows, first, to see the general anomalies as internal and external cleanliness, the sealing surface integrity and the presence of visual external contaminant. A non-identified contaminant of the external surface can potentially contaminate the RF surfaces during the cleaning of the couplers in the US bath, so it should be removed. The most critical anomalies are generally linked to the copper plated surfaces and the ceramic aspect. Concerning the copper plating, the most critical issues are generally blisters, adhesion problems, copper lack, significant scratches, stains and copper particles. Adhesion problems and blisters are generally eliminating criteria. The lack of the copper is tolerated if the surface impacted is at the limit of the copper plating region and have no consequence on the thermal or the RF behaviour (Fig. 4 A). Scratches and brazing rolls (respectively Fig. 4 B/C and Fig. 5) are smoothed using burnishing technics or bead blasting. These technics generally allow to obtain good copper aspect with the right roughness. Copper particles on surface need to be mechanically removed. Afterwards, surface is smoothed using the same precedent technics. Concerning stains, the position we adopt is the following: Stains generated by light oxidation can be tolerated as they would not have significant influence on the PC behaviour. In case of doubt on the origin of the stains, we proceed initially by using alcohol wiping. Afterwards, the contractor prefers using mechanical methods like bead blasting. For the stains treated at the CEA site, we opt for using our standard cleaning procedures using US bath, Tickopur R33 detergent, Sulfamic acid for small oxidation stains (if needed) and RBS T310 detergent for large stains (Fig. 4 E)).

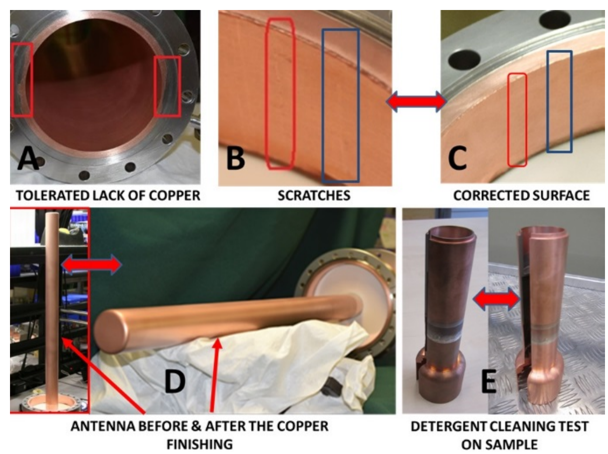

Figure 4: Copper plated surface finishing and cleaning.

Concerning the ceramic, superficial stains on the air side could be removed using sandblasting. For, the vacuum side this operation has to be performed before the TiN deposition.

RELATED TECHNICAL TOPICS

Copper Plating Issues

During the manufacturing of the first IFMIF Series PC pair, copper plating issues have been encountered. Some blisters and skips accrued on the COC copper layer. Therefore, the quality of the copper plating process was tested on samples having the same diameter than the COC but much shorter. The COC is a relatively large part with a diameter of 100mm and about 600 mm long. CPI Investigation showed that, the most influencing cause was not only the size of the plated surface but also the way how this part was handled. The COC is a relatively heavy part

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(about 23kg), which makes its handling by hands relatively difficult. This had an impact on its time of transfer from the different treatment and rinsing tanks used during the preparation and the copper plating. Long exposer to the air seems to be the reason of the local adhesion problems of the copper. After the new optimisation of the transfer of the COC between the different tanks, no major copper plating issue was observed.

Surface Finishing

Depending on the situation, the coupler manufacturer proposed solution to correct imperfection noticed on the copper surfaces.

During the prototype phase, copper wool burnishing was used to remove brazing roll located on the antenna tip at the interface of copper bulk material and copper plating material. This method was successful (Fig. 5). Besides, no impact on the RF behaviour of the PC was seen, during the RF conditioning.

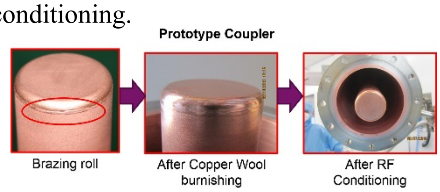

Figure 5: Example of surface finishing result.

In case of discoloration or roughness problems, bead blasting is performed. This solution was suspected to increase the desorption rate of the surface. Measurement performed on the prototype PCs, which have experimented this treatment, showed a desorption rate 3 times less than the specification equal to 5 x 10^{-9} Pa.m/s. The visual aspect of the copper plating is also satisfactory.

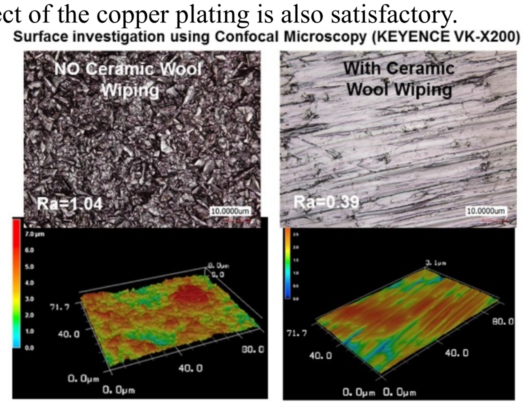

Figure 6: Ceramic wool wiping on copper plated surface.

Ceramic wool wiping is also proposed as surface finishing solution. In addition to the amelioration of the visual aspect, measurement showed the drastic reduction of the roughness (Fig.6) using this technic. Surface investigation didn't show contamination with the ceramic wool.

Copper Baking at 400°C

For the IFMIF PCs, 1µm Ni sublayer is deposed before copper plating. At the end of the process, the Cu layer is heat treated under vacuum at 400°C during 2 hours. This allows the increase of the RRR to higher than 30, in our case. Nevertheless, heat contributes to the diffusion of the Ni in the copper layer, which degrades the RRR value. To determine the diffusion depth of the nickel in the copper player, SIMS measurement was performed on representative sample.

The figure below presents the variation of the Fe, the Ni and Cu from the surface of the copper layer to a depth of 30µm. The thickness of the copper layer was initially measured and estimated to be between 21µm and 25µm. The 1µm Ni layer is supposed to be at this depth.

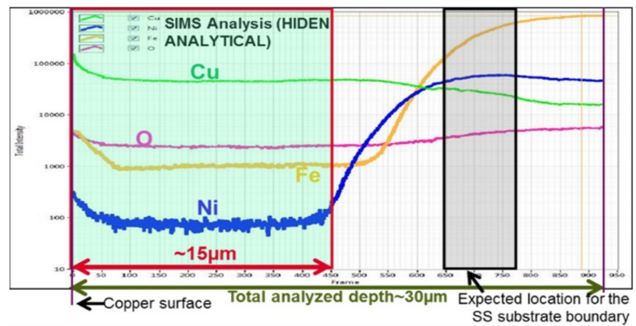

Figure 7: SIMS analysis of a copper plated stainless steel (SS) sample.

It is clearly shown in Fig. 7 that the Ni concentration is relatively stable from the copper surface to 15µm deeper in the Cu layer. Reaching this depth, the concentration starts to increase. The maximum of Ni concentration is obtained at the expected initial position (before heating) of the interface between the Ni layer and SS boundary.

This result shows that with the 400°C treatment Ni and Fe defused less than 10 µm inside the copper. The 15 µm copper layer from the surface to the depth seems to take benefit of the 400°C heating for the increase of the RRR and not to be significantly impacted by the Ni and Fe diffusion. This explains why the global RRR of the entire copper layer increases with the heat treatment.

CONCLUSION

The first IFMIF PC pair is manufactured and shipped. The results of the factory acceptance tests are satisfactory. Finishing operation are discussed an experimented. Their results were evaluated by visual observation, tests on samples or on prototypes. However, RF power test is still the final validation.

Copper plating is probably the most critical operation during the production of the couplers. Investigation on copper coating and check of the its quality need to be one of the major concerns.

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