

VALIDATION OF THE SERIES POWER COUPLERS OF THE LIPAC SRF LINAC

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Abstract

In the framework of the IFMIF/EVEDA project, the cryomodule of the Linear IFMIF Prototype Accelerator (LIPAC) will be assembled in 2019 then tested at Rokkasho. Eight Series Power Couplers (PC) operating at 175 MHz were manufactured under a CEA contract, in order to equip this Cryomodule. They were all successfully RF conditioned up to 100 kW CW in TW and SW configurations. All the high RF power tests were performed under CIEMAT responsibility in BTESA Company premises, according to the CEA requirements.

In order to fix difficulties encountered during the fabrication process, manufacturing and quality control have been analysed in depth. Thanks to the corrective actions implemented, every PC reached the performances targeted for qualification. This paper will give details about this manufacturing phase and provide an overview of the obtained RF test results.

IFMIF POWER COUPLER LAYOUT

The IFMIF Power Coupler (PC) has a $50\ \Omega$ coaxial geometry and consists of three main parts: 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). The layout of the coupler is presented in Figure 1.

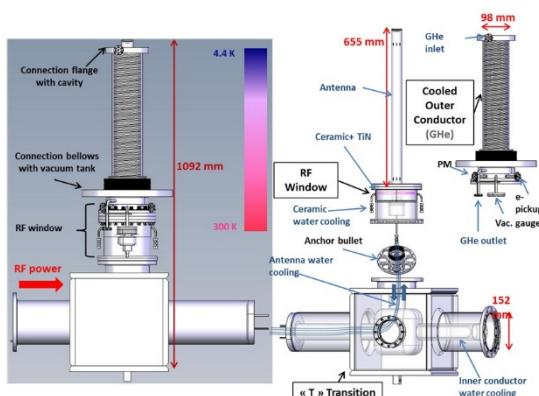


Figure 1: IFMIF power coupler layout.

The connection between the cryomodule and the coupler is guaranteed by a large flange brazed to relatively soft bellows in turn brazed to the outer surface of the COC. These

bellows has a function of a mechanical interface between the coupler body and the cryomodule flange interface, see Figure 1. It was designed to allow strokes of $\pm 4\text{ mm}$ and $\pm 2\text{ mm}$ for respectively axial and lateral directions with low induced mechanical constraints. The aim is to preserve the integrity and the alignment of the cryomodule RF subsystems due to the displacement of the cold mass and the shrinkage of the couplers during the cooldown of the cryomodule. Adapted protection tools were designed by CEA and used to preserve the coupler during the handling and transport operation of the PCs from the reception to the assembly on the LIPAC cryomodule. More details on the PC are presented in [1].

MANUFACTURING OF THE SERIES PCS

Launching of the Series PCs Production

The series manufacturing stage was preceded by a successful prototyping phase [2], [3], [4], [5], [6].

Before the series production a new kick-off meeting took place with the same manufacturer in order to make a statement on nonconformities. Some of the tolerances were relaxed, as the antenna protrusion length, but some minor modifications were also requested, namely, the uses of welded VCR connectors on the helium cooling circuit, instead of the brazed CF interfaces previously used on the prototype.

Production Issues

The manufacturing of the series PC started with major difficulties on validation of the copper plating process. The origin of the issue was not a consequence of a change in the initial procedure but simply some modifications of handling operations on the copper plated parts during the different preparation stages. This change increased significantly the time exposed to the air. Surprisingly this was very impacting for adhesion of the copper plating. This issue was finally resolved after a long investigation and total review of the plating procedure made by the contractor. In parallel to this, many efforts were made to elaborate and test finishing and cleaning techniques in addition to performing several qualification tests of the copper plating on samples as described in [7]. The manufacturing of the first series PC pair was accomplished in April 2016 [7].

During the Site Acceptance Tests performed (SAT) at CEA on the first PC pair, cleanliness and compliance issues were found from the visual inspections. Later, major leak problem was demonstrated on the bellows of the two

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Table 1: Selection of Manufacturing Problems Analysis and Proposed Cures During the Series PC Production Phase

| Problems | Major Causes | The Corrective Actions |
|---|---|--|
| Leaks on bellows | Thin bellows can have their convolutions strongly collapsed during the pump down with some sharp beads between the two surfaces coming in contact. After several pumping and venting operation during the leak tests, a puncture could occur. | <ul style="list-style-type: none"> Replace the bellows by thicker ones to increase mechanical strength. Protect the back surface of the bellows during all the manufacturing stages to avoid dust contamination. Add intermediate leak tests Apply pumping and venting cycling sequences on the bellows to survey their behaviour reproducibility in addition to their tightness |
| Plastic deformation on bellows | Chocks during handling | <ul style="list-style-type: none"> Systematic use of protection tools during all the handling and transport operation |
| Antenna length out of tolerance | Issues during the use of the Coordinate Measurement Machine (CMM). | <ul style="list-style-type: none"> Upgrade of the supporting tools used during the use of CMM Machining of the COC length to get the right antenna tip protrusion length when the coupler is assembled |
| Welding residues inside helium cooling circuit | No flowing of inert gas inside the helium circuit during the welding of the VCR connector | <ul style="list-style-type: none"> Applying of a continuously flowing inert gas during VCR connector welding operation. Control of the inner surface welding quality |
| Sharp brazing wire residue near the ceramic edge. | Brazing process and quality control | <ul style="list-style-type: none"> Better inspection of the ceramics Removal of any sharp edge or suspect metal stains on the ceramics. |
| Cleaning issues and scratches on sealing surfaces | Protection during production process and quality control | <ul style="list-style-type: none"> Ameliorate tools and handling procedure Corrections of degradation Enhance controls and systematic detailed photo reports after each problem detection and for each correction |

couplers [8]. This makes the couplers unusable for the cryomodule operation as bellows represents a vacuum barrier between the ambient air and cryomodule isolation vacuum. However the tightness of these parts were checked at the contractor premises. As consequence, a thorough investigation work was jointly performed by CEA and the manufacturer not only on the received PCs but also on all the other PCs being at that time under manufacturing. A full review of the different production operations was made. This close collaborative work allowed to establish a list of the deviations of some manufacturing and control operations to determine the causes of each production issue and to put in place all the necessary corrective actions.

The table 1 details the problems we treated. These operations took place at very advanced stage of the manufacturing of all the couplers. This was at the origin of heavy manufacturing rework on almost all COCs.

At the end, all the acceptance tests were performed with success. The PCs were cleaned and assembled in ISO5 cleanroom at CEA Saclay for the RF Conditioning.

RF CONDITIONING

RF Performances

After the SAT, the PCs are cleaned and assembled in CEA premises following the procedures already validated during the prototype phase [3]. PCs are then transferred to Madrid in order to be RF conditioned on CIEMAT RF test stand, Figure 2. All the clean assembly operations of PC

pairs on test box and RF test procedures were already established by CEA and CIEMAT teams and validated on prototypes. The conditioning procedure is detailed in reference [5]. All the PCs reached the validation maximum power of 100 kW CW in TW and SW (full reflexion) configurations. This power level allows a comfortable margin for nominal operation RF power on the accelerator varying between 50kW and 70 kW. The SW RF conditioning is performed with 7 short circuit positions allowing to have maximum electrical fields on the ceramics and on intermediate positions. The couplers which had corrections allowing the removal of the sharp brazing wire residue near the ceramic edge (see table 1, line 6) had normal RF behaviour during all the conditioning operations.

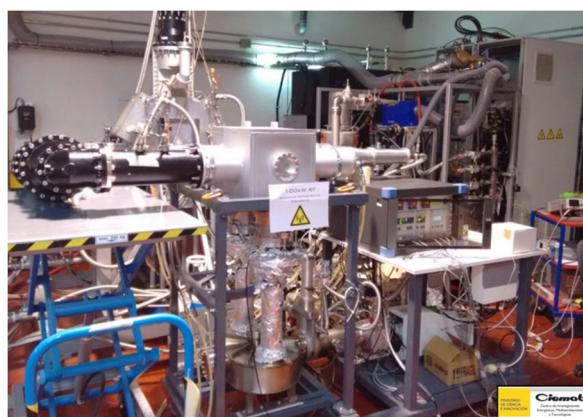


Figure 2: RF conditioning test stand.

Multipacting Behaviour

The PCs named C5 (pair3) and C7 (pair4) showed multipacting (MP) activities between 10 kW and 20 kW in TW configuration generating an important temperature increase always on the middle part of the COC part. The application of magnetic field on this region causes an immediate change of the MP activity. This behaviour was noticed only for duty cycles higher than 10%.

The heating MP taking place on C7 was particularly intense with temperatures going up to more than 100°C if the power is maintained at the MP RF power range. However, once RF power goes out of these power levels the temperature starts to decrease as if power was switched off (see Figure 3).

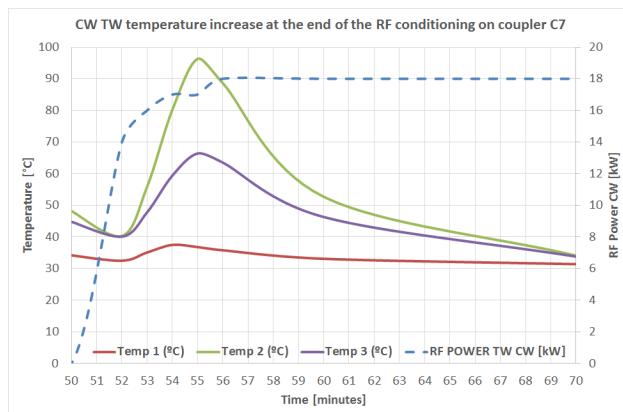


Figure 3: Heating of coupler C7 due to MP.

Some attempts to process this MP level for PC C7 was performed using external blown air cooling. Nevertheless, the temperature increase was too important and not controlled enough to continue this operation. A decision was taken to not completely process this MP. This was motivated by several arguments:

- First, the power ranges corresponding to the heating MP were far below the nominal operating RF power of the PC on the cryomodule.
- Second, during operation, it is always possible to go rapidly through the MP region to limit the temperature increase. Different power increase rates were experimented on PC C7. Results are listed in table 2. They showed that for an initial PC temperature of 35°C, increasing power with a rate of 0.33 kW/s or 0.66 kW/s induces only small temperature increase on MP region.
- Finally, MP level encountered during the test seems to be influenced by the RF configuration due to the assembly on the test box. This was seen by measuring the MP levels when C7 was in downstream position, then, in upstream position for TW configuration. It was expected to have MP in first case for higher input power level comparing to the second case if we assume that RF is perfectly matched all along the COC for the two configurations. Nevertheless, measurement showed a higher MP power level for the up-

stream position of C7. The VSWR is probably not locally the same in the two cases. As a consequence, the MP behaviour is likely to be influenced by some mismatch induced by the test box assembly configuration. Once assembled on cavity to PC will face another RF configuration, so MP behaviour can also be different.

Table 2: RF Power Rate Increase Across Multipacting

| Amp. Rate (W/s) | Max. Pressure (mbar) | Temp at Max. Pressure (°C) | Temp at the end of Ramp(°C) |
|-----------------|----------------------|----------------------------|-----------------------------|
| 40 | 1.3E-07 | 53 | 62 |
| 84 | 1.3E-07 | 45 | 51 |
| 168 | 1.1E-07 | 42 | 48 |
| 336 | 1.0E-07 | 38 | 43 |
| 671 | 9.0E-08 | 37 | 37 |

Vacuum Behaviour

At the end of the RF conditioning, the vacuum level measured for the operating RF power, between 50kW and 70kW, is less than 5×10^{-8} mbar for all the PCs (see Figure 4). For some PC pairs the vacuum starts to increase significantly at the end of the RF conditioning. This was correlated with a temperature increase on the test box and not on the couplers. We can also see that even for couplers were no heating MP was measured their vacuum is degraded for the corresponding power range.

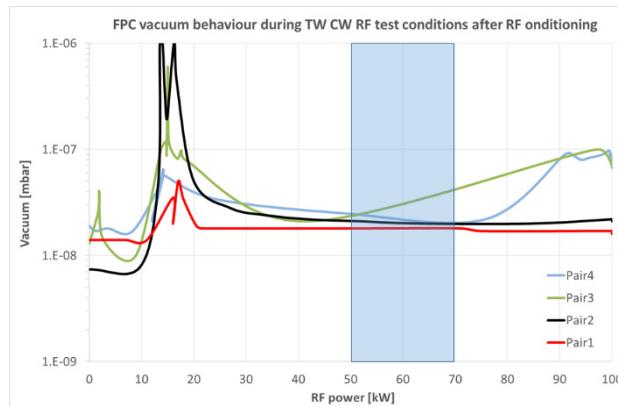


Figure 4: Final vacuum behaviour (TW).

CONCLUSION

Despite the long and successful validation work performed on the Prototype PC, several manufacturing problems were faced during the series manufacturing phase. It is mandatory to keep high exigency and quality control during all the production steps even if all processes seems to be well mastered. Joint efforts, constructive work and very close collaboration between CEA and the coupler manufacturer teams allowed bringing back all the couplers to requested requirements. RF validation tests were performed successfully in CIEMAT RF conditioning test stand with the support of F4E. Assembly of the cryomodule components including these PCs is ongoing.

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