INPUT POWER COUPLER FOR THE IFMIF SRF LINAC

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Abstract

The design phase of the IFMIF-EVEDA Power Couplers for the Superconductive HWR has been accomplished. TiN and copper coatings specifications have been validated on samples. A coupler window equipped with a truncated antenna and RF matching transition have been fabricated and tested to qualify the manufacturing processes and to demonstrate the technical feasibility of the coupler. Series of tests were successfully performed on these subassemblies. The last part of the design phase consists of the design validation by manufacturing two coupler prototypes and testing their performances at full power. Finishing processes and validation tests are on-going.

INTRODUCTION

Design and validation of the first IFMIF cryomodule will be achieved in the frame of the Engineering Validation and Engineering Design Activities program (IFMIF-EVEDA) [1]. This cryomodule will include eight Power Couplers (**PC**), eight superconductive HWRs and eight Solenoid Packages. It was decided that only one coupler design will be used for all the HWRs despite their diverse power needs. PCs should be able to withstand RF power tests up to 200 kW at 175 MHz in CW travelling wave mode and in pulsed full reflection mode.

The coupler design was shared in two parts. The first part, consisting in RF and preliminary thermo-mechanical design, was performed by CEA [2][3]. The second part, consisting in the entire thermo-mechanical design, was accomplished by the company CPI in respect to a detailed Specification and Requirements document edited by CEA [4]. CPI is also in charge of the couplers manufacturing. Close and constructive collaboration between the two design contributors was maintained during the study and realization stages.

Several manufacturing processes and design aspects have been validated before manufacturing the prototypes. Copper plating quality and TiN coating thickness validation tests have been performed on representative samples, in a first stage. Once the full design has been accomplished, a full window set with a truncated antenna and a RF matching transition called "T" transition (Fig. 1) were manufactured. This stage is very important to validate the RF design and discuss the manufacturing quality needed for the prototype PC.

Currently, two prototype PC sets are already manufactured. First validation tests are being performed.

POWER COUPLER LAYOUT

The IFMIF coupler has a 50 Ω coaxial geometry and consists of three main parts: RF window, "T" transition and cooled outer conductor (Fig. 1). In order to reduce the RF power losses heating effects, many design options were decided. Three water cooling systems are used to cool independently the antenna, the inner conductor of the "T" transition and the window ceramic. This ceramic is made of high purity alumina (AL995) to have low tangent delta losses. The anti-multipacting TiN layer thickness on ceramic is also optimized to reduce these losses. Except the "T" transition outer conductor, made of aluminum, 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. This allows more control flexibility on the temperature profile along the cooled outer conductor.

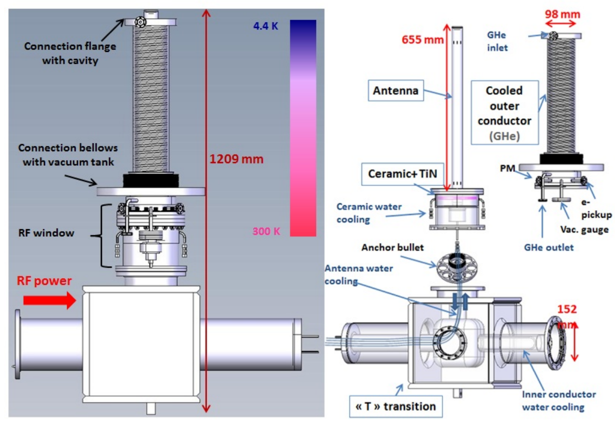

Figure 1: IFMIF Power Coupler layout.

The antenna of the IFMIF PC is made of copper-plated stainless steel. Mechanical calculation showed that bulk copper antenna material choice will dramatically enhance damage risks during the multiple transportation operations of the coupler, as the antenna is relatively long (655 mm).

To reduce the RF mismatching risks, the "T" transition has a frequency tuning port where three different cylindrical plugs can be assembled to allow +/- 1 MHz frequency shift.

An anchor bullet specifically designed by the Mega Industries Company with a quartz dielectric part is used as an assembly interface between the window and the "T" transition. This element has to intercept the assembly mechanical constraints on the ceramic window without having significant influence on the RF matching and losses.

Three diagnostic ports are located near the ceramic vacuum side to measure electron and light generation in addition to the local vacuum pressure during operation.

A large flange joined to a cylindrical bellows set is brazed to the cooled external conductor. This set

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represents the PC interface with the cryomodule and the flexible element needed because of the thermal shrinking of the cryomodule cold mass.

COPPER COATING VALIDATION

The copper coating procedure shall allow a good adhesion of the copper layer, an appropriate RRR and an adequate thickness. The related requirements were the following:

- Thickness = 20 µm (-0 µm; +20 µm)
- $30 \leq RRR_{Cu} \leq 80$

Copper-plated representative samples were used to perform the validation tests.

Thickness Measurements

CPI has delivered a representative sample of the cooled external conductor cylinder made of copper-plated stainless steel, which was cut longitudinally in order to study the copper thickness along the cylinder (Fig. 2). The obtained part was sliced in several samples which were prepared for optical microscopy observation. Thickness measurements showed a copper thickness ranging between 42µm and 50µm. These values are above the specifications but are still acceptable for our design.

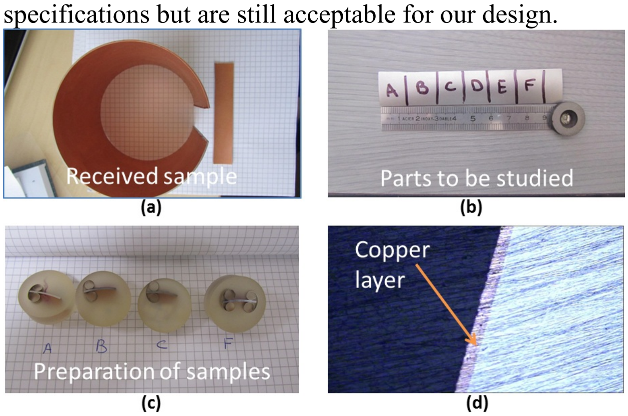

Figure 2: Copper coating measurements.

Adhesion Test

Adhesion tests were performed on the same received sample after copper thickness measurements. Two cycles of thermal shock were performed by alternating liquid nitrogen cooling and immerging in a 65°C heated ultrasonic bath. Neither copper particle losses nor surface damages were observed. An optical microscopy observation of the interface between the copper layer and stainless steel substrate was made. No adhesion problems were noticed

RRR Measurements

RRR measurements were performed on 3 types of samples:

- A stainless steel sample.
- A copper plated stainless steel sample.
- A copper plated stainless steel sample exposed to all the heat treatment procedures expected for the copper coating on the GHe cooled outer conductor.

The RRR value obtained by measuring the thermal resistivity on the received samples is: RRR= 43.

TiN COATING VALIDATION

Experience in RF systems design leads to cover the ceramic windows with a very thin TiN (practically with TiN oxide) layer on the high vacuum side in order to limit the multipacting occurrence and the accumulation of electric charges on the surface. The recommended TiN coating thickness has to be thicker than 5 nm in order to reduce MP but thinner than 15 nm in order to limit the RF losses.

To validate the TiN coating procedure, thickness measurements were performed by two different ways on samples having knowing position on a disc similar to window ceramic during its TiN coating:

- RBS measurements (by JANNUS-CEA) on vitreous carbon samples.
- EDS measurements (by CPI) on ceramic samples with successive plasma etched between measurements to get a measure of thickness and chemistry.

Thickness measurement results (Fig. 3) shows that the coating technique intended to be used for the PC window offers the right thickness in all the ceramic parts. This result was confirmed by the EDS measurements.

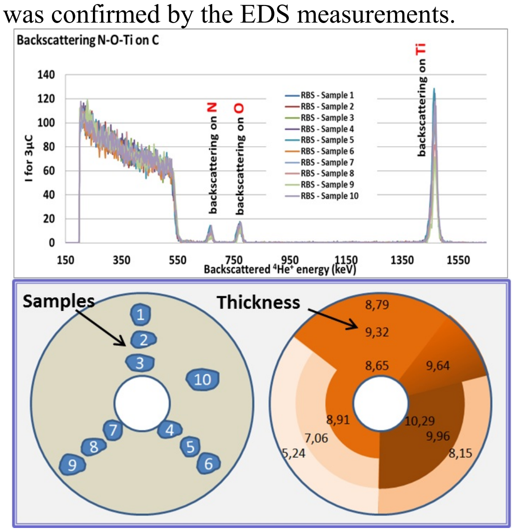

Figure 3: TiN thickness RBS measurements.

WINDOW AND "T" TRANSITION VALIDATION

This stage is very crucial for the decision to order the coupler prototype manufacturing. All aspects and details concerning manufacturing conformity, cleanliness and shipping were considered and detailed in an inspection report. This report is a base document to control the manufacturing finish for all the manufactured IFMIF couplers. The window set has a truncated antenna in order to make low level RF measurement easier. The "T" has the final design requested for the coupler.

A low level RF test stand has been already prepared and calibrated to make the RF validation test. The validation criteria was the following: Each of the "T"

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transition and the window set S_{11} parameter has to be less than -25 dB for any frequency f between 174 MHz and 176 MHz. S_{11} relative to the assembly of these two parts has to fulfil the same condition.

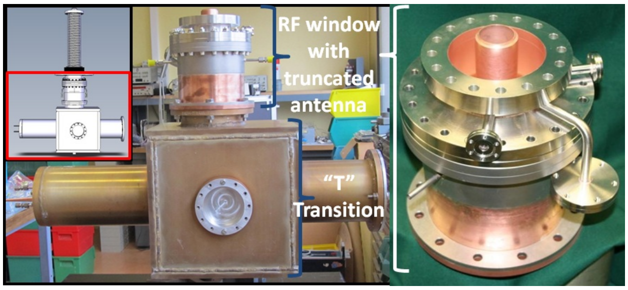

Figure 4: Validation PC parts.

The measured S_{11} of the window was less than -38dB for any frequency between 170MHz and 180MHz. This was the lowest measurable value obtained during the test stand calibration. This is coherent with the very low window S_{11} values obtained by HFSS simulation.

For the “T” transition, S_{11} values were very similar to those obtained for the assembly of the “T” and the window set (Fig. 4). Both measurements fulfil the acceptance condition and demonstrated a low return loss values less than -29 dB for all frequencies between 174 MHz and 176 MHz.

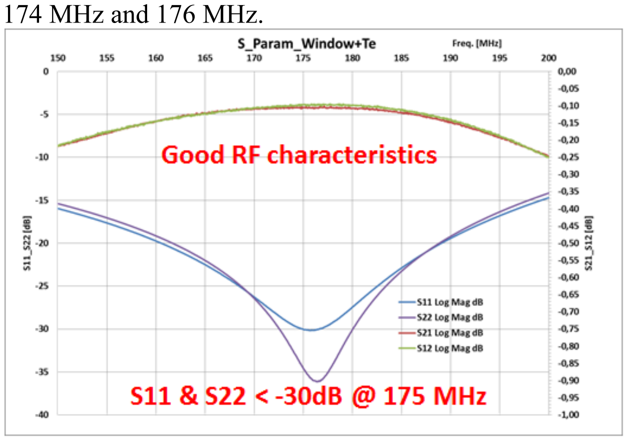

Figure 5: Low level RF measurements on the window and the “T” transition assembly.

Moreover vacuum and water leak checks were successful. Assembly and disassembly of the two coupler parts were performed several times in different configurations with no damages on the ceramic. Some precaution should be taken to guarantee the anchor bullet integrity.

FIRST COUPLER PROTOTYPES

Two coupler prototypes were ordered after the previous validation stages. One of the most delicate manufacturing operations was the assembly of the double walled cooled outer conductor (Fig. 6. b)). A particular assembly procedure for the inner and outer GHe cooling systems walls was already experimented on other different PCs. The inner conductor is cooled in liquid nitrogen where the outer conductor is heated to 300°C. Then, inner conductor is rapidly passed through the outer conductor to avoid the thermal expansion of these parts before reaching the final position. This operation is relatively delicate as the two conductors are quite long.

Figure 6: a) Power coupler prototype. b) GHe cooling inner wall (on the left) with engraved cooling channels and outer wall (on the right) with a smooth cylindrical shape.

Two full prototypes PC were manufactured (Fig. 6. a)). The GHe cooling systems were assembled with success. A series of acceptance tests will be performed prior the PC reception and preparation for the room temperature RF conditioning tests.

CONCLUSION

Several validation stages were performed prior to the PC prototypes manufacturing. Test results were generally satisfactory. Two coupler prototype sets were manufactured. Acceptance tests are on-going. The reception of couplers is planned for summer 2012. The RF power processing will be the next major validation stage.

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