STATUS OF THE CW POWER COUPLERS FOR THE SRF LINAC OF THE IFMIF PROJECT*

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Abstract

The driver of the International Fusion Material Irradiation Facility (IFMIF) consists of two 125 mA, 40 MeV CW deuteron accelerators. A superconducting option for the 5 to 40 MeV linac based on Half-Wave Resonators (HWR) has been chosen. The first cryomodule houses 8 HWR's supplied by high power RF couplers; each of them should be able to operate at 200 kW in CW. This paper will give an overview of the RF design of the 175 MHz CW power coupler. The detailed mechanical studies and the fabrication will be performed by an industrial company. Global approach of the contract and the organization of the intermediate validation tests will be discussed. In a second part, the choices made and the progress of the couplers RF power test stand will be described.

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). Eight power couplers, eight superconductive HWRs and eight Solenoid Packages will be needed for the tests. It was decided that only one coupler design will be used for all the HWRs despite their diverse power needs. The coupler should be able to operate at 200 kW CW RF power at 175 MHz in travelling wave (TW), but should also be tested in full reflection mode. The total number of couplers needed for the IFMIF project will be 84.

The IFMIF coupler design and validation tasks are as follows [1]:

- RF power couplers design and manufacture.
- RF power couplers test stand design and implementation.
- RF couplers conditioning at room temperature.
- Integration of couplers to the cryomodule and final conditioning with the HWRs.

The preliminary design of the coupler has already been carried out and an industrial company has been chosen to achieve the detailed thermo-mechanical studies and manufacture the couplers. The Contractor will be in charge of several design aspects detailed in this paper. Furthermore, the design of a test-box, needed to achieve the RF matching of the couplers during their RF conditioning, is underway in parallel.

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This paper will give a description of the IFMIF coupler, the global approach for the detailed design and future tests and the status of the design of the test-box for couplers test stand.

PRELIMINARY DESIGN OF THE POWER COUPLER

General Description

The IFMIF coupler has a 50 Ω coaxial geometry and consists of three main parts (Fig.1) [1] [2]:

1. The RF window and the antenna part, which will be maintained at 300 K during operation and it includes:
   - An AL300 WESGO coaxial disk ceramic window allowing the separation of the cavity vacuum from the external atmospheric pressure.
   - A copper antenna allowing the RF power matching to the beam.
   - A warm external conductor, brazed on the ceramic disk, with 3 ports close to the ceramic for diagnostics and appropriate sites for thermocouples engraved through the copper bulk.
   - A water cooling system for the antenna.
2. The cooled external conductor part, which is a cylindrical double wall tube cooled with helium gas. It

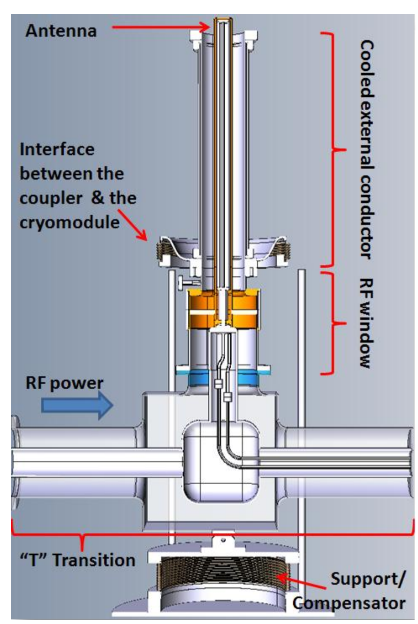

Figure 1: The IFMIF power coupler.

the coupler window at 300 K to the cavity at 4.4 K.

3. The "T" transition part, which is an interface between the RF window and the input power coaxial line. Water pipes can pass through this part in order to feed the antenna cooling system.

Two other mechanical elements are also needed during the operation of the couplers in order to protect them against mechanical constraints due to the thermal shrinking and the cryomodule pumping-down. These elements are the following:

- The mechanical interface between the coupler and the cryomodule.
- The "T" transition support frame and compensator system.

Design Aspects

RF and multipacting as well as thermal calculation results were detailed in [1] and [3].

The RF design was optimized for a ceramic having a thickness of 10 mm and a relative dielectric constant ε_r of 9.5. A final optimization of the ceramic thickness can be made once the real value of ε_r is obtained for the operating frequency of 175 MHz (Fig.2). Our aim is to keep the minimum reflection frequency value as close as possible to the operating frequency, despite the low S_{11} calculated values for the window.

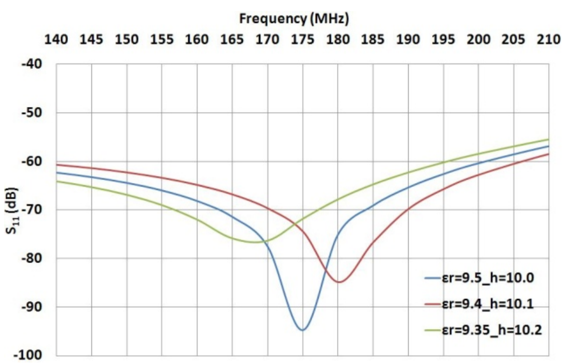

Figure 2: Example of optimization of the ceramic thickness (simulation made with perfect conductors).

To prevent multipacting problems on the ceramic, 10 nm TiN layer will be deposed on its vacuum side. A sapphire window equipped with a photomultiplier will be used to measure the light generated by electron activities near the ceramic. Nearby, an electron pick-up and a vacuum gauge will also be used. Associated to an interlock system, these diagnostics will offer the possibility to switch-off the power very rapidly in case of a multipacting establishment.

APPROACH FOR THE COUPLER DETAILED DESIGN

Prior to the launching of the contract, the RF coupler preliminary design, the helium cooling circuit design and the preliminary drawings were already achieved. CPI industry was selected to accomplish the coupler detailed design in respect to the Specification Document [2]. The Contractor will be in charge of the thermo-mechanical studies of the entire coupler set. The water cooling system of the antenna has to be optimized and cooling systems for the eventual overheating of the ceramic and the "T" transition during the coupler operation, have to be studied. Moreover, a detailed mechanical design of the coupler set (including the support frame and the compensator system) and an assembly procedure have to be performed. All the design results and manufacturing procedure choices have to be detailed prior to the production of the couplers. Two coupler prototypes will be achieved for qualification of the design, and then couplers for the series will be manufactured.

Validation Tests

Several validation tests and intermediate steps are detailed in the couplers Specification Document [2]. The most important step is the fabrication of a window mock-up identical to a final window, but with a truncated antenna (Fig.3). This mock-up must undergo all tests needed for the validation of the final version of the window. Then, this mock-up with a "T" transition will be qualified with low level RF measurement. A dedicated RF connector will be designed to fulfil the RF matching of standard measurement connectors to the truncated antenna. The S_{11} parameter of the mock-up, the "T" transition and these two elements assembled together should meet the following condition: $S_{11} < -25$ dB for all frequency between 174 MHz and 176 MHz.

Repetitive assembly and disassembly tests will also be performed on these coupler parts.

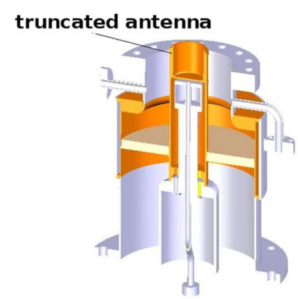

Figure 3: The window mock-up.

The approval for the coupler prototype manufacturing will take place once the following validation test will be performed [2]:

- RRR measurements on copper.
- Surface aspect and layer thickness control of the deposed copper layers.
- Copper coating adhesion test.
- Characterization tests of the TiN deposed layer.
- Desorption rate tests.
- Leak tests.
- Pressure test for the helium cooling circuit.
- Low level RF tests.
- Assembly and disassembly of the mock-up and the "T" transition.

All the manufacturing steps must respect strict cleanliness conditions.

TEST-BOX FOR THE COUPLER RF CONDITIONING

Power couplers are usually RF conditioned by pairs at room temperature. An appropriate test-box (or matching box), on which two couplers can be assembled, should be used. The RF design of the test-box should allow a very good RF matching of the two couplers and efficient pumping of the entire vacuum volume. The test-box design should also be optimized in order to reduce its heating and size, and make simpler its manufacturing, handling, assembly and cleaning.

Several factors could enhance the design issues for this test-box. The wave length is relatively large for the operating frequency of 175 MHz. This implies too large test-box geometries for the simple parallelepiped shapes. The coupler RF conditioning is planned to be performed at a maximum power of 200 kW both with TW and full reflected wave for all RF phases. This could imply high thermal losses and a cooling system will be probably needed. Besides, for the IFMIF coupler, the distance between the antenna extremity and the flange plan is very short (29 mm), see Fig.4. This limits the penetration of the antenna inside the test-box and reduces the RF coupling dramatically.

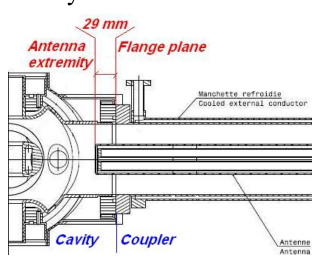

Figure 4: The antenna penetration.

Several test-box models were studied in order to obtain the largest bandwidth and lowest losses. The problem of the short antenna penetration can be overcome by adding a "cup" structure enhancing the capacitive coupling to the antenna, see Fig.5. The best results were obtained for what was called the Stadium Structure shape.

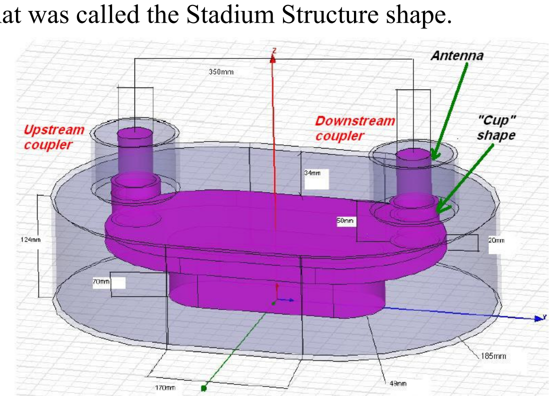

Figure 5: The test-box Stadium Structure shape [4].

A test-box made with an internal structure in copper and an external box in stainless steel, could be the optimal option. Its bandwidth for S_{11} < -30 dB is about 4.9 MHz as shown in Fig.6 [4]. The worst overall dissipated power will be about 1.5 kW for 200 kW input power in SW mode. Maximum power density (around 40 kW/m^2) occurs at the bottom of the stainless steel box, whereas the heating of the internal copper structures shows lower values.

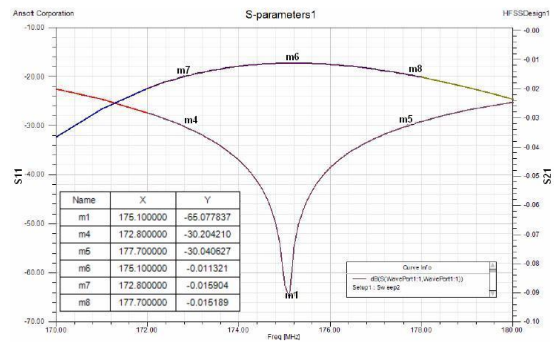

Figure 6: S-parameter results for the Stadium Structure.

A water cooling system will be designed to reduce the thermal gradient in the test-box. Concerning the pumping port position, it was demonstrated that it can be placed at the bottom of the structure without a high RF field disturbance. More global studies considering the vacuum and thermal influence on the test-box detuning are in progress. To compensate these effects, two options are investigated: mechanical deformation of the test-box and use of plungers.

CONCLUSION

The RF preliminary design of the IFMIF coupler was fully accomplished. The thermo-mechanical detailed design and the manufacturing of these couplers will start this year. The design studies of the test-box for the couplers RF conditioning tests is also in progress in parallel. A preliminary RF design model was achieved. Additional mechanical and thermal studies are needed before the validation of this model.

ACKNOWLEDGMENTS

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REFERENCES

[1] "Preliminary Design Report of the IFMIF-EVEDA SC DTL", CEA-Saclay, 1st-2nd July 2009.

[2] "Specification and requirements of the RF couplers", IFMIF-EVEDA-ASG-DL09-S010-A, 25/09/2009.

[3] J. Plouin et al, "Main choices and preliminary design for the IFMIF RF couplers", SRF Conference, Berlin, 2009.

[4] F. Mirapeix, C. Palacios, "Preliminary Design of a Test Box for the IFMIF-EVEDA Couplers" (V 3.0), TTI, Santander, Spain, 2010.