

MAIN CHOICES AND PRELIMINARY DESIGN FOR THE IFMIF RF COUPLERS

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Abstract

IFMIF (International Fusion Material Irradiation Facility) is the future neutrons irradiation facility that aims to qualify advanced materials for the fusion reactors successor to ITER (International Thermonuclear Experimental Reactor) [1]. The required neutrons flux is created from the irradiation of a lithium target by two high intensity deuteron ion beams (125 mA @ 40 MeV CW) produced by two parallel linear superconducting accelerators. The niobium cavities are Half Wave Resonators (HWR) at 175 MHz operating at 4.4 K. All cavities are equipped with the same power coupler designed to transfer a maximum power of 200 kW in CW. The present phase of the project, IFMIF-EVEDA, for Engineering Validation and Engineering Design Activities, is aimed at the validation of the technical options for IFMIF, by the construction of an accelerator prototype: 1 cryomodule with 8 HWRs and 8 couplers providing RF power up to 70 kW. Nevertheless, these couplers are designed to be able to operate at 200 kW, and they will be tested and RF conditioned at this power level. This paper describes the overall operating requirements of these high power couplers, presents the main choices that have been made up to now and the RF design of the coupler components.

THE IFMIF-EVEDA PROJECT

The IFMIF-EVEDA program has been launched in June 2007, with the following objectives:

- Validate the technical options for the construction of an accelerator prototype, with a full scale of one of the IFMIF linac, from the injector to the first cryomodule.
- Provide the complete engineering design report for the construction of the IFMIF accelerators.

The driver of IFMIF consists of two 125 mA, 40 MeV Continuous Wave (CW) deuteron accelerators. Superconducting (SC) Half-Wave Resonators (HWR) will be used for the 5 to 40 MeV Linac [2]. The SC linac for EVEDA Accelerator prototype (1 cryomodule of IFMIF) contains all necessary equipments to transport and accelerate the required deuteron beam from an input energy of 5 MeV up to the output energy of 9 MeV. It is mainly composed of 8 SC HWRs for beam acceleration, working at 175 MHz and at 4.4 K, 8 RF power couplers providing 70 kW in TW, and 8 Solenoid Packages (SP) as focusing elements [3]. It will be the first cryomodule of IFMIF.

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RF COUPLERS REQUIREMENTS

All the components of the IFMIF accelerator (RFQ, bunchers, HWR) will be fed with 2 different RF power ratings : 20x105 kW and 32x200 kW, see Fig. 1. One single type of coupler will be used for all HWRs, designed for a maximum power of 200 kW.

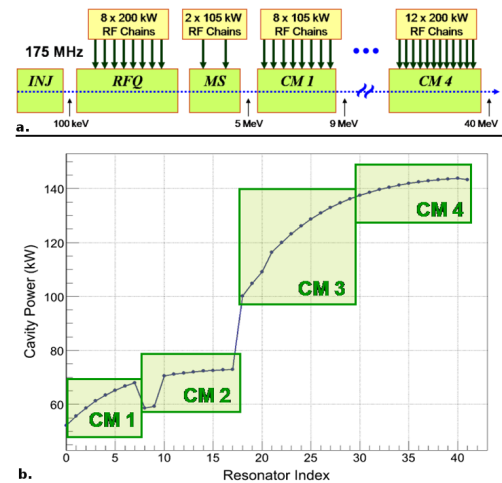


Figure 1: Scheme of the RF sources for the IFMIF accelerator (a). RF power per cavity (b) CM is for cryomodule.

The couplers developed during the present EVEDA phase will have a design allowing them to be used under the IFMIF operating conditions. They are aimed to operate at 70 kW on the EVEDA cryomodule. However they will be tested and RF conditioned at 200 kW in CW. The conditioning will take place at CIEMAT.

The RF couplers have to protect the vacuum of the cavities. They have to assure the thermal transition between the cavity at 4.4 K and the room temperature.

The RF couplers are connected to the sources using standard coaxial lines.

RF COUPLERS DESIGN

A general overview of the coupler set is shown on Figure 2. The coupler has a coaxial geometry, and is connected between the HWR and a “T” transition box. It is constituted of a cooled external conductor, a warm window and an antenna.

The coaxial geometry has been chosen for the window, with a coaxial ceramic disk separating the cavity vacuum from air and with a copper antenna. The impedance matching is achieved by changing the diameters of the inner and outer conductors. The impedance is kept at 50 Ω . The

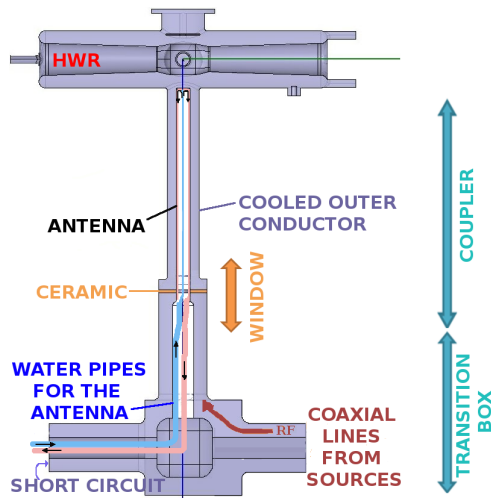


Figure 2: Overview of the coupler with the transition box and the cavity.

coaxial connected to the T transition is a standard $6 \frac{1}{8}''$. The very good reflexion coefficient of this window was calculated (see Fig. 3): $S_{11} < -90$ dB at 175 MHz, $S_{11} < -50$ dB in the frequency range (0-200 MHz).

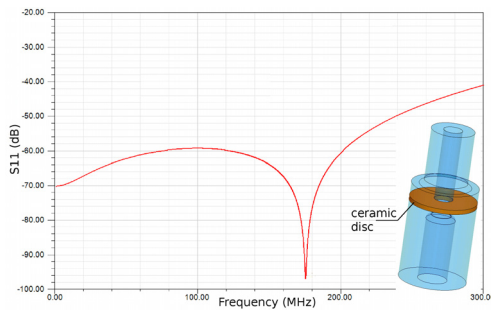


Figure 3: Reflexion diagram of the coaxial window with ceramic disc.

Multipactor simulations have been carried out, with MUPAC code [4], in the vacuum side of the window, with starting points near to the ceramic on the outside conductor. The results are given on Figure 4 for two cases : traveling wave (TW) and standing wave (SW), the latter case corresponding to a total reflexion inside the cavity. This window is free from multipactor in TW up to 120 kW, which is interesting for the EVEDA phase where the couplers operate at 70 kW. Moreover the multipactor in the coaxial line around the antenna is expected only under 50 kW in TW (Fig. 5).

All the couplers fabricated in the frame of EVEDA will be tested and RF conditioned up to a maximum power of 200 kW, on a dedicated test bench, then on the machine.

Antenna's Length

In SW, the field pattern and the thermal losses in the window are correlated to the distance between the ceramic and the cavity. The electric field around the ceramic has to be

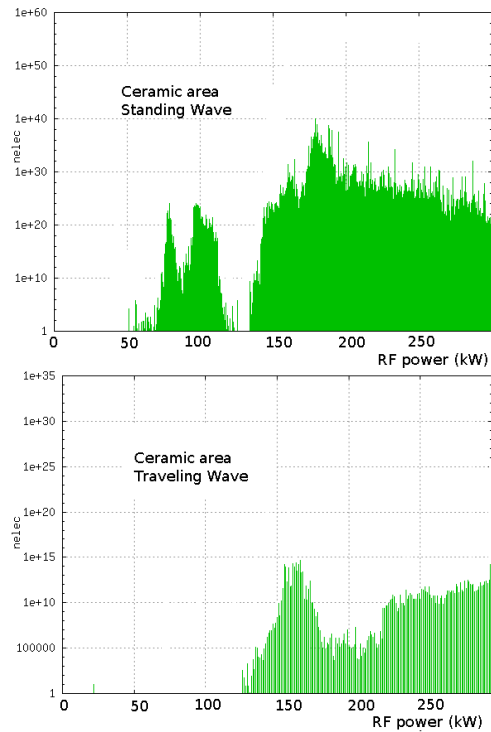


Figure 4: Multipactor near to the ceramic.

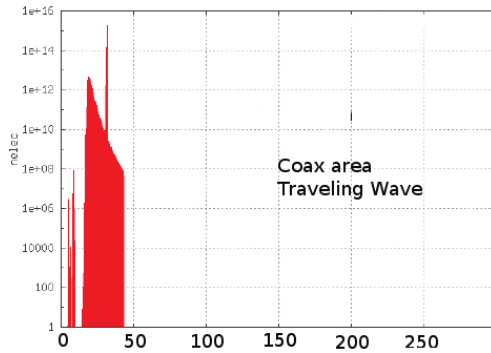


Figure 5: Multipactor in the coaxial line around the antenna.

limited because it induces thermal losses and multipactor. The distance $\lambda/4$ ($=430$ mm), where this field is maximum, must be avoided. On the other hand, the coupler has to fit under the cavity in the cryomodule, where beam axis is fixed at 1.5 m from the floor (see Fig. 6). The distance between the ceramic and the cavity has then been fixed to 670 mm.

The coupling between the antenna and the HWR is given by the quality factor Q_{ext} , calculated with the formula :

$$Q_{ext} = \frac{V_{cav}}{(r/Q) \cdot I_b \cdot \cos(\phi_s)}$$

V_{cav} being the cavity voltage, I_b the beam current, ϕ_s the synchronous phase and r/Q the ratio of the shunt impedance to the quality factor of the cavity. The beam current is 125 mA, and the r/Q calculated for the HWR

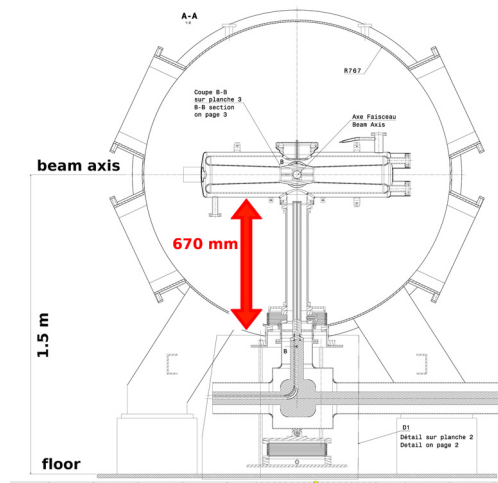


Figure 6: Length of the antenna.

is 148 Ω. The cavity voltage and the synchronous phase are given by the beam dynamics for each HWR. Q_{ext} has been calculated with the beam dynamics data, in order to fit for all the HWRs, and is equal to 5.7×10^4 . To achieve this coupling, the distance between the extremity of the antenna and the cavity axis was fixed to 121 mm.

COOLING SYSTEMS

Antenna

The cooling system placed inside the antenna has two main functions :

- keep the whole antenna at the room temperature to avoid radiation inside the superconducting HWR (radiation power is proportional to T^4)
- avoid temperature gradient around the ceramic (to limit constraints)

We chose to cool the antenna with water. Thermal simulations with the code CASTEM show that the temperature of the whole antenna is then kept at $300 \text{ K} \pm 1 \text{ K}$ both in TW and SW for 200 kW input power. In these simulations, the ceramic's dielectric loss tangent is 5×10^{-4} , and the window's surfaces exposed to the RF are in copper with conductivity 6×10^7 . The temperature gradient ΔT inside the ceramic in SW is shown on Figure 7 in two cases:

- window's outer conductor cooled with blowing air (a): $\Delta T_{max} = 9K$
- window's outer conductor in static air (b): $\Delta T_{max} = 15K$

These values are lower in TW (resp. $\Delta T_{max} = 4K$ and $\Delta T_{max} = 7K$).

Cooled External Conductor

The cooled external conductor assures the transition from 4.4 K to 300 K. The cooling will be achieved with

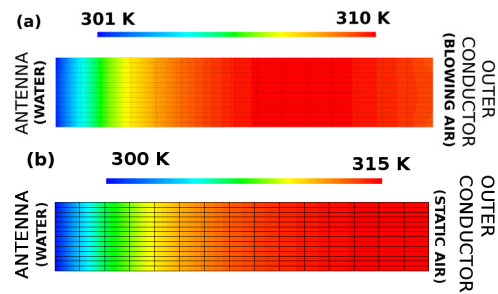


Figure 7: Temperature pattern in the ceramic in SW for 200 kW input power. Antenna cooled with water, outer conductor of the window in blowing (a) and static (b) air.

helium gas, driven by a double-walled outer conductor (Fig. 8). The maximum of RF heat transfer is estimated at 300 W/m^2 .

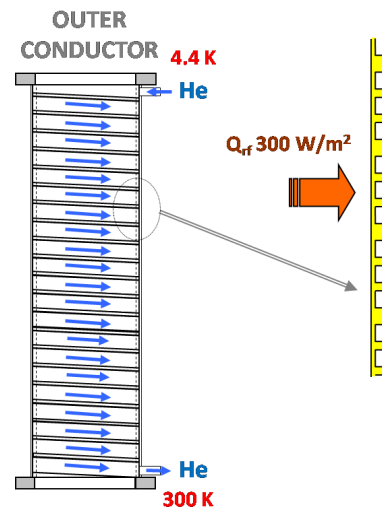


Figure 8: Helium cooling from 300 K to 4.4 K of the double-walled outer conductor.

TRANSITION BOX

The implementation of a “T” transition box has been decided to allow the connection of the water pipes to the cooling system of the antenna (see Fig. 2). The RF design of this transition box has been adapted to the nominal frequency of 175 MHz. This box should be tunable in a range of $\pm 1 \text{ MHz}$, by using a circular aperture in one of its walls allowing the penetration of a cylindrical plug. The box matches three coaxial wave guides, one being connected to the RF window, the second to the input RF line while the third one is closed by a short-circuit. All these coaxials are standard 6 1/8”.

BIASING AND DIAGNOSTICS

Biasing

For the future IFMIF accelerator, remains the possibility of polarizing the coupler to shift multipactor barriers. This will need a modification of the design of the transition box allowing insulation.

Diagnostics

Diagnostics will be implemented to detect electronic activity in the vacuum side near to the ceramic: a vacuum gauge, an electron pick-up and a light detector.

MECHANICAL DESIGN AND TESTS

Mechanical Design

The mechanical design will be subcontracted to the company that will manufacture the couplers. The call for tender of this market is still in preparation. The order is foreseen before the end of 2009.

High Power Tests and RF Conditioning

The high power tests and the RF conditioning of all the couplers will be realized at CIEMAT up to 200 kW in CW. CIEMAT will be in charge of the realization of the RF test bench.

IMPLEMENTATION IN THE CRYOSTAT

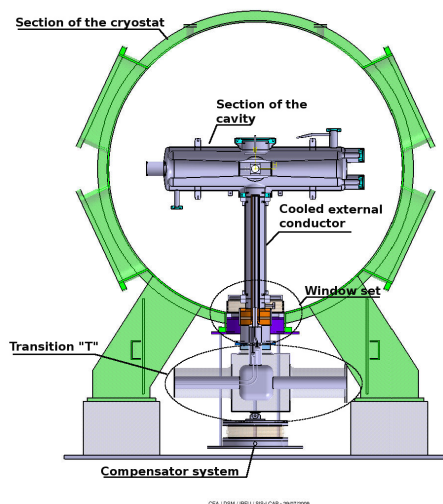


Figure 9: Implementation of the couplers in the cryostat.

Figure 9 shows the implementation of the couplers in the cryostat during the EVEDA operation. The couplers will be in vertical position, in order to limit mechanical stresses produced by the antenna's weight and vibrations on the ceramic. They will be situated under the cryostat, due to surrounding constraints. The connection to the cryomodule

will be assured by a support for the "T" transition box and by a compensation system to ensure the integrity of the mechanical interfaces during pumping and cool-down phases. These elements are not designed yet.

CONCLUSION

In the frame of IFMIF-EVEDA, RF couplers will be fabricated and tested at 200 kW CW at 175 MHz. The RF design of these couplers has been achieved, and consist of a coaxial window with a ceramic disk. RF, multipactor and thermal calculations have been carried out. The antenna will be down cooled with water and the external conductor with helium gas. The mechanical design still has to be studied.

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