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MYRRHA 80 kW CW RF COUPLER DESIGN

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Abstract

MYRRHA [1] (Multi Purpose Hybrid Reactor for High Tech Applications) is an Accelerator Driven System (ADS) project. Its superconducting linac will provide a 600 MeV - 4 mA proton beam. The first project phase based on a 100 MeV linac is launched. The Radio-Frequency (RF) couplers have been designed to handle 80 kW CW at 352.2 MHz.

This paper describes the thermal, mechanical and RF studies leading to the final design of the RF coupler.

INTRODUCTION

The coupler aims to transfer energy from the RF source to the accelerating cavities of the linac. It also provides a vacuum and a thermal barrier between air and the superconducting cavity while preserving its cleanliness. The coupler allows some mechanical flexibility to compensate differential thermal expansions and mechanical misalignments. As part of an ADS, the MYRRHA coupler is laid out for the highest achievable reliability. To improve the reliability, the coupler is operated well below its maximum performance (nominal power is 8 kW CW and 20 kW CW in the fault-tolerances schema [2]) and the redundancy of the diagnostics is used (example: two vacuum gauges used rather than one).

DESIGN OVERVIEW

The power coupler is made of three main elements (Fig. 1):

- A ceramic window with an inner coax (antenna) and an outer coax (shaft) brazed on a high purity alumina ceramic,
- A double input tee, with, on one side, a flange to bring RF power, and on the other side, a special short stub, to bring cooling pipes all the way up through the antenna,
- A barometric compensator, to minimize mechanical load on cavity. This load is due to differential pressure between inner cryomodule pressure and atmospheric pressure.

The coupler allows some mechanical flexibility to compensate differential thermal expansions and mechanical misalignments thanks to bellows.

The resistance of the RF coupler submitted to various sets of operation static loads (differential pressures and connection efforts from RF bellows and compensator bellows) has been checked by using finite element simulations: substantial safety margins have been observed for all simulated configurations.

The absence of modal frequency under 50 Hz has also been verified, as requested by the specifications (Fig. 2).

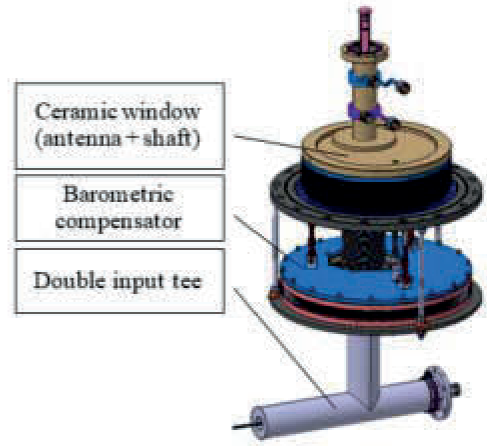

Figure 1: Main elements of the power coupler.

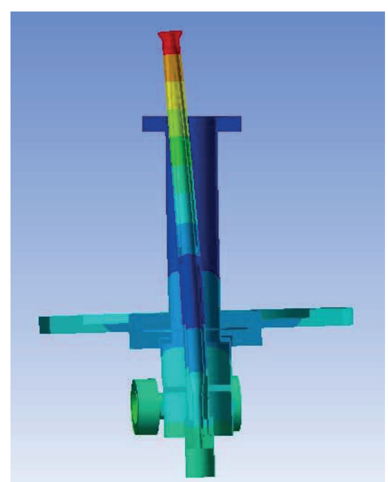

Figure 2: First vibration mode (antenna bending) at 72 Hz, cut view.

THERMAL BEHAVIOUR

The power coupler must not transmit excessive heat load to the superconducting Spoke cavity. This heat load is the sum of two components:

- A conductive component through the shaft of the coupler which links the barometric compensator at ambient temperature to the Spoke cavity at 2 K.
- A radiative component of the coupler hot surfaces towards the inner cold surface of the Spoke cavity.

Distributed heat sources originate from the Joule effect induced by the RF waves at the outer surface of the coupler antenna, at the inner surface of the outer conductor and from dielectric losses in the ceramic disk.

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An inner water flow cools the antenna, two cryogenic loops at around 10 and 60 K provide thermal barriers on the shaft.

A semi analytical model has been used for an estimation of temperatures and heat loads on the cryogenic loops and on the connection to Spoke cavity, i.e. conductive component. Input parameters of the model are power deposition at a given RF power, water flow in the antenna, and outer conductor structure (stainless steel thickness, copper plating thickness and copper Residual Resistivity Ratio). All used material properties are temperature dependent.

Obtained results at a 80 kW RF power for the final design are summarized Fig. 3. Maximal temperature is 25°C at the tip of the antenna, thermal loads are 2.3 and 8.8W on cryogenic loops at 10 and 60 K, and 0.4 W on the Spoke cavity connection. Finally, no excessive load is observed.

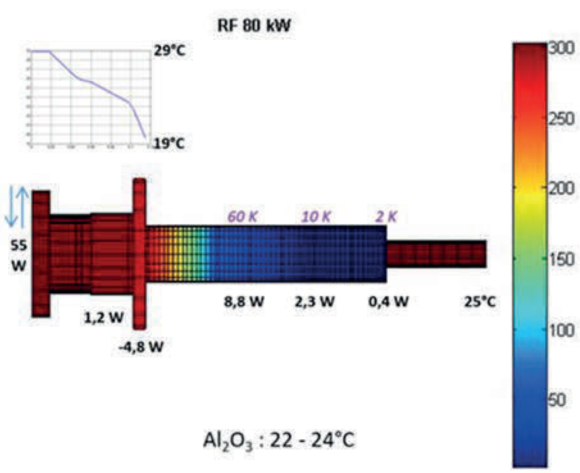

Figure 3: Temperature colour map (K) and resultant temperature (°C) and load (W) at particular sections of the coupler for 80 kW RF power. Coupler is tilted for plot convenience.

The radiative component of the heat load on the cavity has been estimated by combining previous temperature map with analytically defined view factors. For an alumina emissivity of 1 and a copper emissivity of 0.1, this radiative component is less than 0.4 W.

RF OPTIMISATION

To optimize the RF design of the coupler, simulations were performed to reach:

- A maximal power transmission while keeping a simple fabrication design,
- A limited electric field to avoid breakdowns and reduce power losses as well (for cryogenic aspects),
- An adequate coupling to the cavity, to guarantee the nominal voltage in the cavity gap as a function of the load introduced by the beam,
- A reduced multipacting phenomenon.

The 3-D HFSS code (from ANSYS) has been used for the electromagnetic simulations and MUSICC3D code [3]. (from IN2P3/IPNO) for the multipacting simulations.

With the tolerances' effects and realistic variations of the materials properties, results remains under specifications.

Power Transmission Optimization

RF coupler is based to a 3" 1/8 EIA coaxial line with an alumina disk to guarantee vacuum tightness. The presence of this disk creates a local mismatch.

The RF coupler design in the window region has been optimized to minimize the reflected power.

We get S_{11} < -50 dB at 352.2 MHz (Fig. 4), a much better performance than the specification of S_{11} < -30 dB (99.9% transmitted power).

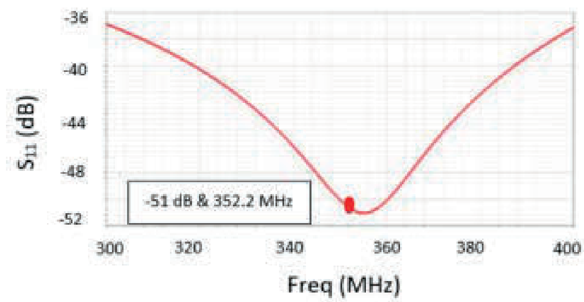

Figure 4: S11(dB) versus the frequency (MHz).

Other power transmission optimisation was made in order to allow the introduction of the antenna cooling system through the inner connector. The solution: an adaptation of a stub in short circuit placed in parallel as show in Fig. 1.

Electrical Fields

RF coupler has been designed to handle 80 kW CW in traveling mode operation. The maximum of electric field obtained (0.5 MV/m@80kW) is below the specification (1 MV/m). The maximum of the electric field at the triple point (ceramic - metal and air/vacuum) is 0.27 MV/m @ 80 kW, to be compared to the specification of 0.3 MV/m. Figigure 5 shows the electric field in the window region at 352.2 MHz and for 80 kW CW.

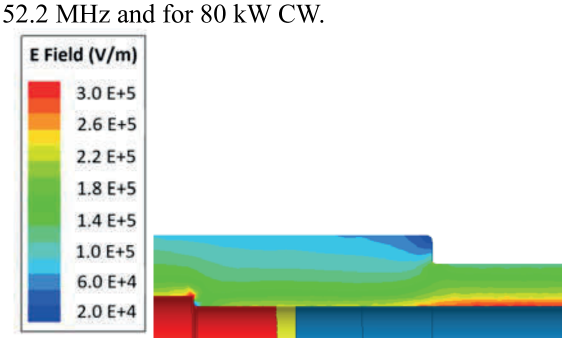

Figure 5: Electric field at 352.2 MHz @ 80 kW CW.

Chokes closed to the window have also been studied but the simulation results have been comparable with and without chokes. Therefore the design without chokes was preferred for ease of machining.

Coupling to the Cavity

Different types of antenna tip have been studied (spherics, flat, ...). The 'mushroom' design below (Fig. 6) has been chosen for its lower penetration into the cavity. For

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the same voltage in the gap, the electric field remains constant at the tip of the antenna and the frequency perturbation induced to the cavity is low (2 kHz).

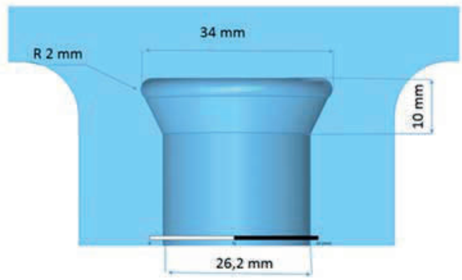

Figure 6: Design of the chosen antenna's tip.

For all the accelerating cavities, a common, not adjustable, antenna penetration is used. So, this penetration must be chosen in order to optimize the minimum RF mismatch in nominal conditions for all the Spoke cavities.

For the chosen design, the specification of Qext = 2.2 $\times 10^6$ is met with 96.5 mm of antenna's penetration (measured from the cavity flange).

Multipacting

Multipacting is an undesired phenomenon of resonant electron build up encountered in electromagnetic field regions under vacuum. It appears when an electron is accelerated by the electric field and hits the enclosure's wall. Depending on the secondary electron yield of the wall, more than one electron can be emitted and accelerated by the electric field, creating a self-sustained electron avalanche.

By simulation, we found only one multipacting barrier at 67 kW @ 0.37 MV/m. Fig. 7 shows the charge number from MUSSIC3D (the sum of secondary electrons) versus the peak electric field.

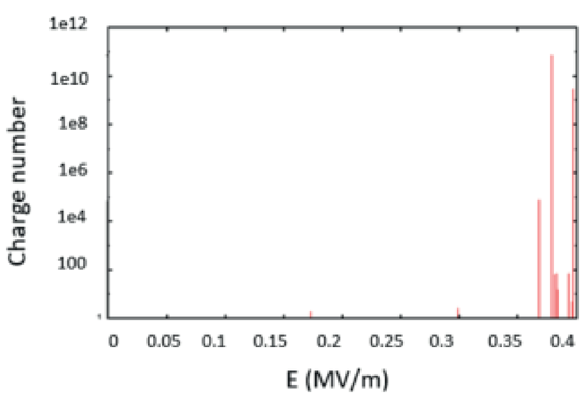

Figure 7: Charge number versus the maximum electric field (MV/m).

Moreover, the multipacting at 67 kW has no resonant electron trajectories impacting the alumina disk of the coupler. So theoretically there is no risk to break the alumina.

MANUFACTURING

Engineering phase is now done and calls of tender have been sent (April 2019). High technical skills are required to manufacture such products. A special attention is paid concerning the following operations:

- Ceramic brazing: it has to resist to the thermal dilatations of the different material (alumina, stainless steel and copper) and guarantee high vacuum inside the cavity,
- TiN coating on alumina ceramic,
- Copper coating on stainless steel shaft.

CONCLUSIONS

The design of the RF couplers for the Spoke cavities of the linac was performed. All the simulation results are much better than specifications. The calls of tender have been launched in April 2019 for four prototypes, two with TiN coating on the alumina disk and two without coating.

The goal is to received couplers prototypes early 2020 for RF conditioning and test on the cavity prototypes. Then a series of 50 couplers is planned.

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