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STATUS OF THE HIGH POWER COUPLERS FOR ESS ELLIPTICAL CAVITIES

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Abstract

In the framework of the European Spallation Source (ESS), CEA Paris-Saclay is responsible for the delivery of 30 cryomodules (9 medium beta (beta = 0.67) and 21 high beta (beta = 0.86) ones). Each cryomodule contains 4 elliptical cavities equipped with a radio frequency (RF) power coupler. The ESS nominal pulse is 1.1 MW maximum peak power over a width of 3.6 ms at a repetition rate of 14 Hz. The design of the couplers for medium beta and for high beta cavities is the same, except a small difference of the antenna penetration to adjust the Qext. The mass production of the 120 couplers started and all the medium beta couplers have been conditioned at room temperature. The first cryomodules equipped with the power couplers were successfully tested at high RF power and with cavities at 2 K reaching the ESS nominal pulse. The main issue at the start of the series production could be fixed and it was due to bad TiN coatings that caused abnormal dielectric losses in the window. Thus, this paper deals with the TiN coating defect, presents the conditioning procedure and gives a conditioning report of these 36 couplers.

INTRODUCTION

For the delivery of 120 couplers (36 medium beta and 84 high beta couplers) to the ESS accelerator, CEA Paris-Saclay launched a contract with the company PMB to manufacture the couplers. The production is divided into different phases with milestones: the first step consists in the production of six pre-series medium beta couplers to validate the manufacturing process, the second phase corresponds to the manufacturing of the other medium beta couplers and finally, the high beta couplers are supplied in a third step. Currently, we have completed the conditioning of all the medium beta (MB) couplers at CEA and that in spite of a TiN coating problem after the 6 pre-series couplers. Thus, in this paper, after a brief description of the couplers and the conditioning preparation at CEA, we will deal with the TiN coating issue and we will report the conditioning results.

ESS HIGH POWER COUPLERS

The coupler is composed of three main parts (see Fig. 1): a single window with its antenna, a double-wall tube and a doorknob transition [1]. The coupler works at 704.42 MHz for a maximum peak power of 1.1 MW and a nominal pulse 3.6 ms at the repetition frequency of 14 Hz.

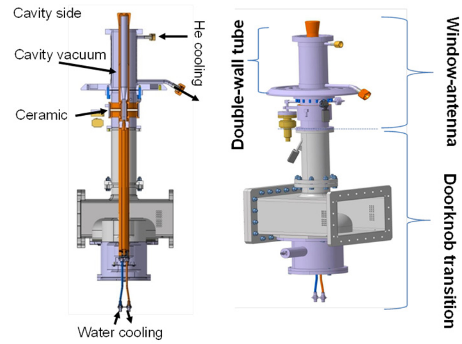

Figure 1: Architecture of the coupler.

The couplers are common to medium and high beta cavities except for the length of the double-wall tube (the medium beta one is 0.4 mm shorter to adjust the antenna penetration and consequently the Qext).

The inner conductor of the coupler is cooled with water and on the vacuum side of the ceramic, a TiN coating is performed (thickness 10 nm +/- 5 nm).

At CEA Paris Saclay, we prepare the couplers for the conditioning. Consequently, we clean the couplers (tube in an ultrasonic bath with Tickopur R33, manual cleaning with ethanol for window and RBS T310 detergent for the antenna). Then, the couplers are assembled on a coupling box in a ISO5 cleanroom (see Fig. 2) and finally we perform a baking of the coupler at 170 °C for 4 or 5 days in an oven.

Figure 2: Assembly in cleanroom.

As we have two klystrons at CEA, we have the possibility to perform the conditioning of two couplers pairs in parallel. The conditioning consists in doing RF power ramp from 10 kW to 1.1 MW for different pulse widths and repetition frequencies in travelling waves and standing waves (with two positions of the short circuit) [1]. During the conditioning, we control the RF powers, vacuum, electric activity (electric arcs and multipactor), temperature and water flow. After the conditioning, we transfer the couplers to the industrial company that mounts couplers on cavities and then assembles the cryomodule at CEA. The three first

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cryomodules for each type of cavity (medium or high beta) are tested in nominal conditions at CEA [2].

TIN COATING

On the window ceramic, a TiN coating is performed with the sputter deposition method and after the ceramic brazing. To check the compliance of the TiN coating (composition and thickness 10 nm), we decided to put vitreous carbon samples (10 mm x 10 mm) in a window mock-up and a sample on the window flange (see Fig. 3); then we perform stoichiometric measurements (with the X-ray Photoelectron Sprectrometry method) and SIMS (Secondary Ion Mass Spectrometry) characterizations on the samples.

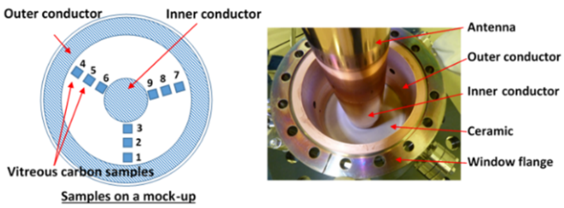

Figure 3: TiN samples and window.

Before the coating of the 6 pre-series MB couplers, we validated the TiN layer on samples (e.g. sample 2 in the mock-up: Ti=42.2 %, N=31.7 %, O=24.5 %, thickness=8.2 nm). Then, we conditioned these 6 MB couplers without problems (at average power 55 W in travelling waves, the maximum temperature of the couplers monitored on the external surfaces of the window close to the ceramic reaches 38 °C). Unfortunately, for the first pair of series MB couplers, a crack occurred on the ceramic in travelling waves (14 Hz, 800 µs, 800 W) and we lost the vacuum tightness. After analysis, we saw that the window temperature increased highly (+22 °C instead of +1.6 °C in the same RF power ramp for the pre-series couplers, see Fig. 4). The 2 following series couplers presented the same temperature behaviour and consequently we decided to stop their conditioning when the coupler temperature reached 60 °C and before a possible crack.

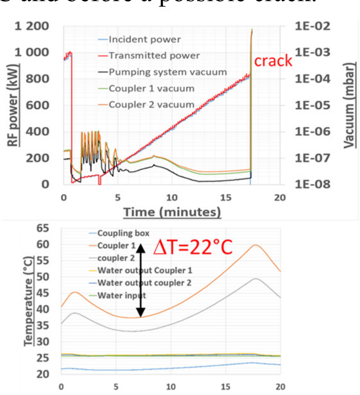

Figure 4: Temperature increase before crack.

We also stopped the production of the other MB couplers to find the origin of the problem. We tested a coupler without TiN coating and on this coupler, the RF conditioning was successfully completed in travelling waves (in standing waves, the conditioning failed due to multiple electric arcs): the coupler temperature in travelling waves was similar to the one obtained on the pre-series couplers. Thus, the manufacturing process except TiN coating phase was not the cause of the problem.

In parallel, a ceramic put on a window mock-up was TiN deposited and characterized in terms of dielectric properties. This ceramic (whose metallization for the brazing was removed) was measured in a resonant cavity at 1.8 GHz. This measurement correlated with finite element method simulations gave $\varepsilon r=9.44$, tan $\delta=2.04\times10^{-3}$. For the same characterization on a ceramic without TiN coating we obtain: $\varepsilon r=9.47$, tan $\delta=2.78\times10^{-4}$, compliant with the manufacturer data. So, the TiN layer of the first series MB couplers generates the equivalent of dielectric losses increased by a factor of 10. This result was also confirmed with temperature simulations of the window where only an increase of the dielectric losses of the ceramic (by a factor of 10) allows us to reach the temperatures obtained on the series window (see Fig. 5).

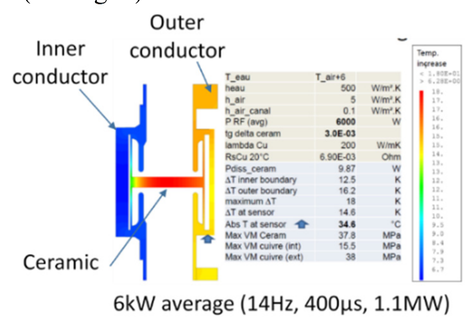

Figure 5: Temperature simulation of the window.

Some tests and adjustments of the TiN coating machine were done but unfortunately the TiN layer remained dissipative and we never succeeded in obtaining the same TiN layer as for the pre-series MB couplers. Finally, the couplers manufacturer changed its TiN subcontractor and began a new validation process (always with the sputter deposition method). For that, we kept the previous tests (stoichiometric and thickness measurements) on vitreous carbon samples and we add supplementary tests: RF low level characterization of a ceramic with TiN layer in transmission and reflection modes, visual inspection of the ceramic color and DC resistance measurement of the TiN layer with a multimeter.

Finally, the current properties of the new TiN layer are: thickness 6 nm, stoichiometry on vitreous carbon samples: Ti=19.9%, N=18.2%, O=25.1%, C=36.5%, the titanium is present in TiO_2, TiO_xN_y and TiN forms. The dielectric characteristics of a ceramic with the new TiN coating are $\varepsilon r=9.46$, tan $\delta=2.65\times10^{-4}$, similar to the properties without TiN layer. During the RF conditioning, we add a security to switch off the RF power if the window temperature becomes higher than a threshold defined by the operator (e.g. 45 °C).

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THE MB COUPLERS CONDITIONING

With the new TiN coating, we conditioned all the series MB couplers. Our criteria to valid the conditioning are as follows:

- Whole RF time in travelling waves lower than 120 hours.
- Outgassing in the nominal ramp (3.6 ms, 14 Hz, from 10 kW to 1.1 MW) followed by a 1 hour plateau at 1.1 MW lower than 2×10^{-8} mbar in travelling waves. During this RF sequence, no electric activity (multipactor and electric arcs) must occur.
- Outgassing in the ramps (500 µs, 14 Hz, from 10 kW to 1.1 MW) and 3.6 ms, 14 Hz, from 10 kW to 300 kW) lower than 2×10^{-8} mbar in standing waves (for the two positions of the short circuit). During these RF ramps, no electric activity must occur.

During the conditioning of the MB couplers, we can meet three kinds of behaviour in travelling waves: no outgassing during ramp and the plateau (see Fig. 6), constant outgassing during the plateau (see Fig. 7), or a "random" outgassing during the plateau (it means very short outgassing sometimes, see Fig. 8).

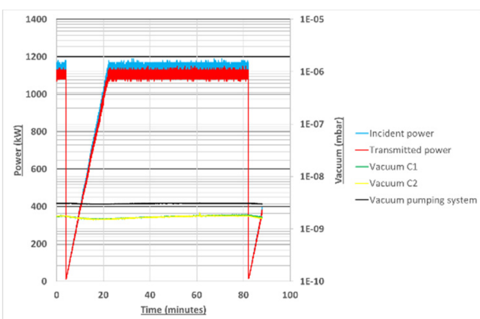

Figure 6: No outgassing.

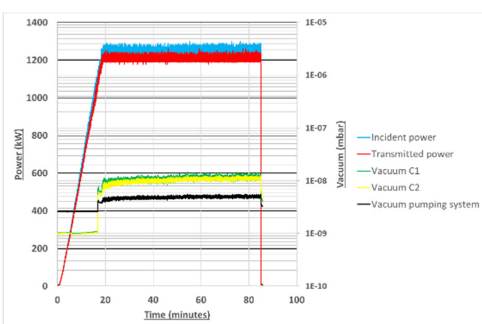

Figure 7: Constant outgassing.

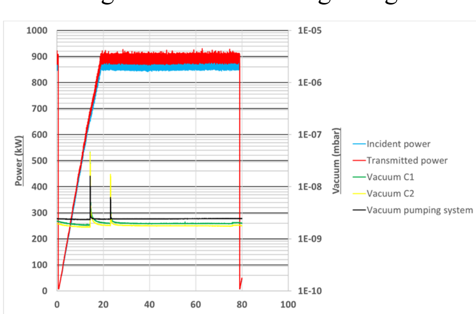

Figure 8: "Random" outgassing.

Concerning the maximal temperature on the window external surfaces, we reach a value of about 40 °C (see Fig. 9). Except for a few couplers, the conditioning criteria are respected (see Fig. 10): the 2 pairs with excessive conditioning time are couplers for which we tried to improve performance but finally in spite of a long RF power time, their features did not change. The outgassing higher than our threshold is a very "narrow band" outgassing.

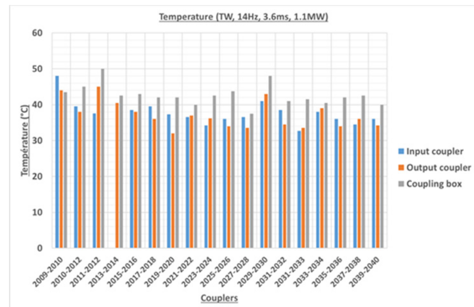

Figure 9: Temperature in travelling waves.

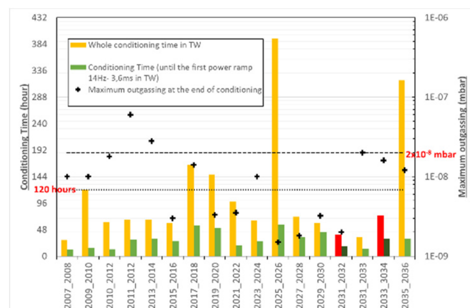

Figure 10: Time and outgassing.

For the standing waves, the couplers were also compliant with our criteria: for the position of the short circuit where we have the maximum electric field close to the ceramic, we have no parasitic activity; for the other position (minimum electric field close to the ceramic), an outgassing lower than our threshold is present.

CONCLUSION

The 36 medium beta couplers (6 pre-series and 30 series couplers) have been successfully conditioned. The TiN coating defect met at the beginning of the series couplers was solved by changing the TiN subcontractor and by adjusting parameters of the TiN machine.

We have validated the minor changes in the high beta couplers and launched their production. The 4 first high beta couplers will be delivered at CEA in June 2021.

REFERENCES

[1] C. Arcambal *et al.*, "Conditioning of the first mass production power couplers for the ESS elliptical cavities", in *Proc. 19th Int. Conf. RF Superconductivity (SRF'19)*, Dresden, Germany, Jun.-Jul. 2019, pp. 288-292. doi:10.18429/JACoW-SRF2019-MOP086

[2] C. Madec *et al.*, "The ESS elliptical cavity cryomodule production", presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May 2021, paper WEXB01, this conference.