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CONDITIONING OF THE FIRST MASS PRODUCTION POWER COUPLERS FOR THE ESS ELLIPTICAL CAVITIES

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Abstract

In the framework of the European Spallation Source (ESS), CEA Paris-Saclay is in charge of the delivery of 9 medium beta (beta = 0.67) and 21 high beta (beta = 0.86) cryomodules. Each cryomodule is composed of 4 cavities equipped with RF (Radio Frequency) power couplers (704.42 MHz, 1.1 MW maximum peak power, repetition rate=14 Hz, RF pulse width > 3.1 ms). Ten prototype power couplers have been manufactured to validate the design and the performance. Currently the mass production of the 120 couplers started and the six first pre-series medium beta couplers have been successfully conditioned. The achievement of this milestone allowed us to launch the production of the remaining 30 medium beta couplers. This paper presents the conditioning of the pre-series couplers.

INTRODUCTION

After the successful conditioning of the medium and high beta coupler prototypes [1,2], the CEA Saclay launched the mass production of the 120 couplers. In a first step, six medium beta couplers have been manufactured and tested to validate their performance and the manufacturing process. This paper describes the main features of these pre-series couplers, the whole infrastructure developed at CEA to perform the conditioning of the coupler with the cleaning, the assembly, the bake-out and the conditioning test stand. Finally, we present some results of the conditioning.

ARCHITECTURE OF THE COUPLER

The coupler is composed of three different parts: a window with its antenna, a double-wall tube and a doorknob transition. The windows and the doorknob transitions are common to the medium and high beta couplers. Only the length of the double-wall tube differs: the high beta tube is about 3 mm longer than the medium beta one. For the mass production, all the coupler components are manufactured by the same company.

Window

The window is composed of a single alumina disk to ensure the tightness between the cavity vacuum and the ambient air. Close to the ceramic, chokes allow to obtain the best RF matching around the operational frequency. The window is composed of copper for the antenna and the choke parts and of stainless steel 304L for the other parts. The different elements are brazed together except the antenna that is welded. On the vacuum side of the ceramic, a TiN deposition (10 nm ± 5 nm thickness) is performed after brazing. RF surfaces of stainless steel parts are coated with copper coating (30 µm ± 10 µm thickness). The antenna made from bulk copper is electro-polished then electron beam welded to the main window assembly.

The antenna is cooled thanks to an internal water cooling circuit. The window is presented in Fig. 1.

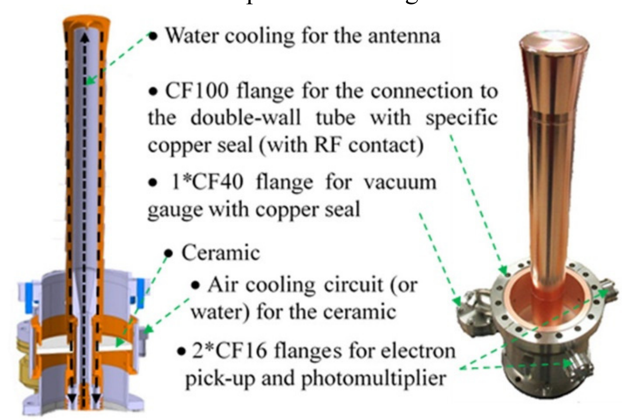

Figure 1: Window and its antenna.

The cooling circuits are tested for tightness and for pressure. A vacuum leak test and an insulation test are carried out on the window.

The window is equipped with different diagnostic components:

- An electron pick-up to check the possible multipactor phenomena but also to obtain the image of the RF power at the ceramic level. The length of the pick-up antenna is determined to obtain a 80 dB RF coupling in travelling wave (TW). The pick-up is composed of a brazed ceramic and a molybdenum antenna (see Fig. 2),
- A view port equipped with a photomultiplier used for arc detection (see Fig. 2),
- A IKR070 vacuum gauge from Pfeiffer.

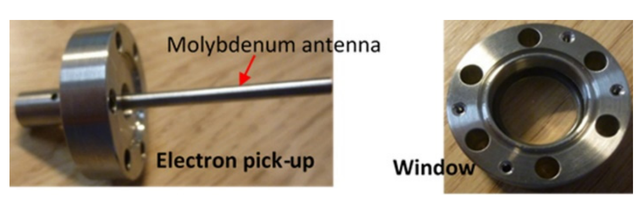

Figure 2: Electron pick-up and window for view port.

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Double Wall Tube

The function of the double-wall tube is to ensure a thermal gradient between cavity (2 K) and the ambient temperature (window level) and to be used as the external conductor for the RF coaxial line. Stainless steel 316L is used for the double-wall tube. A cooling circuit (Helium) is used to obtain the required thermal gradient. Details are represented in Fig. 3.

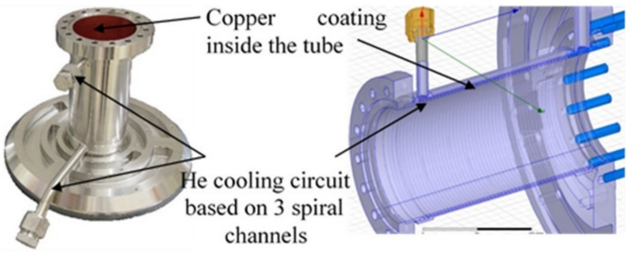

Figure 3: Double-wall tube.

To ensure the correct flow of helium in the cooling circuit, the two walls of the tube are assembled by a shrink-fitting method. All parts are welded. A copper coating (10 µm thickness) is also performed inside the double-wall tube. The helium circuit is tested for pressure and for leak tightness.

Doorknob Transition

The doorknob transition performs the link and the matching between the waveguide and the coaxial configuration of the coupler line. The doorknob is equipped with a port to put a photomultiplier in order to detect electrical arcs at the window ceramic level and a high voltage connector for antenna biasing (max 10 kV).

The inner conductor has a water cooling circuit (in full RF power, the water temperature increases by less than 1 °C for a water flow around 2.5 l/min). This cooling circuit is directly connected to the antenna cooling circuit, see Fig. 4.

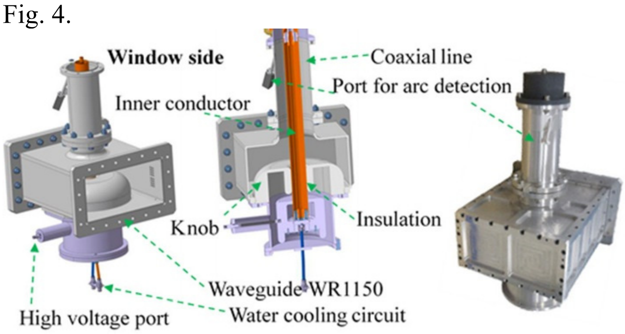

Figure 4: Doorknob transition.

Test Box

To perform the conditioning, a pair of couplers is put on a metallic (316L) test box allowing a correct transmission of the RF power between the two couplers.

This box is vacuum tight thanks to a seal (an aluminum wire) between the cover and the box bottom. The box has a window for arc detection (used with a photomultiplier) and a pumping port, see Fig. 5.

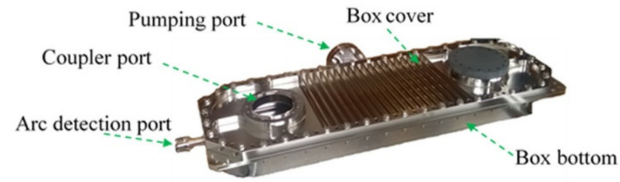

Figure 5: Test box.

INFRASTRUCTURE AT CEA SACLAY

The couplers are delivered disassembled at CEA Saclay. Each component of the couplers is individually inspected; then the double-wall tubes and windows are stored in nitrogen cabinets before assembly on the test box. The first step of the preparation is the cleaning.

Cleaning

The double-wall tubes are cleaned in an ultrasonic bath with Tickopur R33 (dimension of the container: 500x500x1400 mm^3, features of the ultrasonic generator: 25 kHz, 3000 W). The tubes are immersed in the bath for 10 minutes then rinsed with water. If some oxidation marks remain present, a manual cleaning with RBS T310 is performed, see Fig. 6.

Concerning the windows, they are manually cleaned with absolute ethanol on the external surfaces, under the chokes and in all the ports with microfiber swabs. The antenna is cleaned with RBS T310 then rinsed and dried.

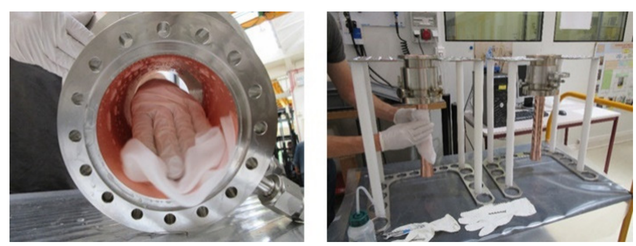

Figure 6: Cleaning with RBS T310.

The electron pick-up is cleaned in a metallic beaker filled with absolute ethanol and the beaker is put in an ultrasonic bath.

Then, all the components are transferred in an ISO7 cleanroom and finally in ISO5 to be assembled.

Assembly

In the ISO5 cleanroom, the coupler components are installed on their support to be dried. a particle counting is then performed on the tubes and the windows. If no particle greater than 0.3 µm is detected, the assembly can start with putting the window on the tube then the two components are set up on the test box, see Fig. 7.

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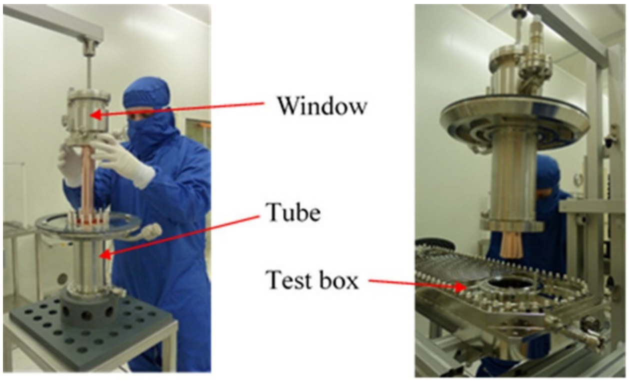

Figure 7: Assembly in cleanroom.

The last step of the assembly is a vacuum leak test. The couplers and the test box are under vacuum (in the range [10^{-7};10^{-6}] mbar). If the leak test is ok, the couplers are left under vacuum then transferred outside the cleanroom.

As the weight of the couplers on the box is around 110 kg, the transfer is carried out on some rails set up on lift tables and test benches.

Bake-Out

After the assembly in the cleanroom, the couplers on their test box are moved in the conditioning area. A low level RF measurement is performed with a vector analyzer and coaxial adapters to check the assembly. The reflection and transmission coefficient are respectively represented in Fig. 8 and in Fig. 9.

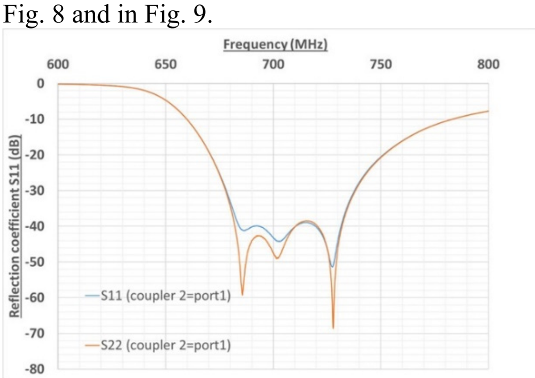

Figure 8: Reflection coefficient.

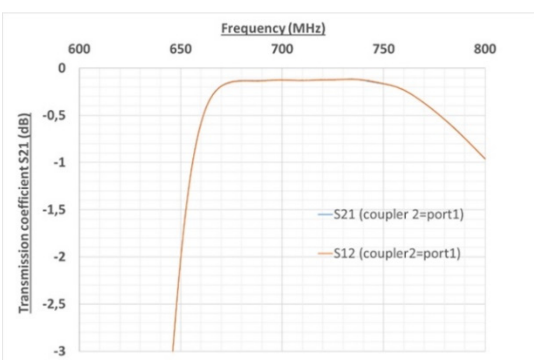

Figure 9: Transmission coefficient.

If the RF results are correct, the couplers are then put into a furnace and connected to a pumping system, see Fig. 10.

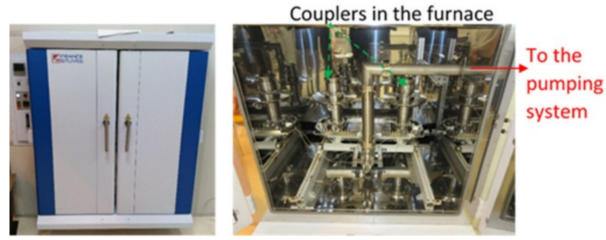

Figure 10: Furnace for couplers.

The couplers and the test box are baked out for 4-5 days at 170 °C while the pumping system is baked out at 120 °C for the 2 first days of the baking and then 60 °C. The temperature rise (or fall) from ambient temperature to 170 °C lasts 2.5 hours. During the bake-out, a nitrogen atmosphere is established in the furnace to limit the oxidation of the copper on the air side of the windows. An example of a temperature cycle followed by the first couplers pair of the pre-series is given Fig. 11.

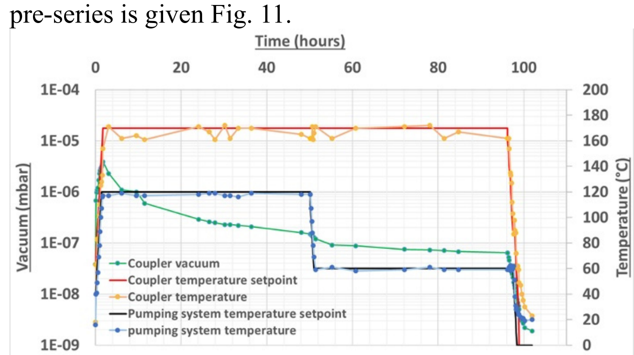

Figure 11: Temperature cycle.

In order to increase the efficiency of the baking, all test boxes are baked out without couplers beforehand.

Conditioning Test Stand

The couplers are conditioned by pair on a test box: coupler 1 is on the klystron side and coupler 2 is on the load side. The couplers pair is installed on a specific test bench composed of a pumping system and a tool to install the doorknobs. The calculated effective pumping speed at the pumping port is 19 l/s.

Measured signals: During the conditioning, different elements are checked and controlled. The diagram of the test stand is represented in Fig. 12 where the terms 1 and 2 correspond to coupler 1 and coupler 2 respectively. Concerning vacuum, we check:

- The vacuum of each coupler thanks to the IKR070 gauges set up on the vacuum ports (signals VAC1 and VAC 2),
- The vacuum of the pumping system with a IKR070 gauge. This gauge is close to the input of the pumping port of the coupling box.

For the electrical activity, we check:

- The presence of electrical arcs with photomultipliers on the air side of the ceramic (PMA1 and PMA2) and also on the vacuum side (PMV1 and PMV2). We also detect the electrical arc activity in the coupling box thanks to a photomultiplier set up on the test box (PMB),

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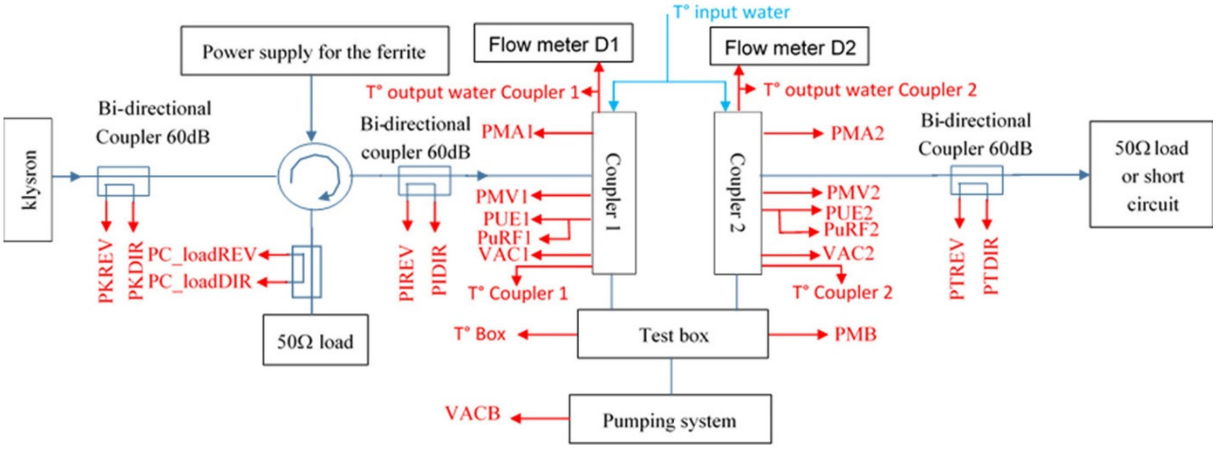

Figure 12: Diagram of the test stand.

- The multipactor effect with the electron pick-up of each coupler (DC bias of 48 V) thanks to the signals PUE1 and PUE2.

In terms of RF power, we control:

- The incident power at the output of the klystron (signal called PKDIR),
- The reverse power at the output of the klystron (signal called PKREV),
- The incident power at the input of the couplers (signal called PIDIR),
- The reverse power at the input of the couplers (signal called PIREV),
- The incident power at the output of the couplers (signal called PTDIR),
- The reverse power at the output of the couplers (signal called PTREV),
- The image of the RF power in the coupler thanks to the electron pickup (signal PuRF1 and PuRF2).

Concerning the water, two flowmeters allow the control of the water flow at the output of each coupler cooling circuit. The temperature of the water is also checked with a probe at the water input and two probes at the water output of each coupler.

A temperature probe is installed on each coupler (on the cooling circuit of the ceramic) and a third one is put on the test box.

The whole conditioning test bench is represented in Fig. 13.

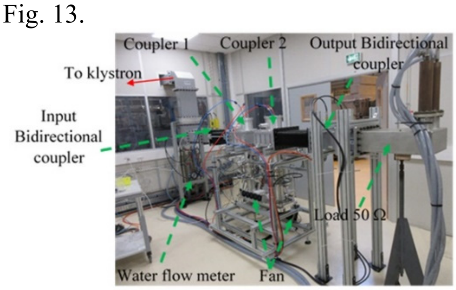

Figure 13: Conditioning test stand.

Conditioning principle: For the conditioning, we perform RF power ramps from around 10 kW to 1.1 MW. We switch off the RF power when one of the following events occurs:

- Outgassing with a vacuum level exceeding a hardware threshold defined at $1x10^{-6}$ mbar,
- Presence of electrical arcs whose intensity is greater than around 3 lux (photomultiplier),
- Presence of electrons whose intensity is greater than 8 mA (detected with the pick-up electron).

The RF power is increased step by step (usually 1 kW per second). The power increases as long as the vacuum pressure is lower than a software threshold (usually defined at $2.5x10^{-7}$ mbar). If the outgassing is too important (it means greater than this threshold), we decrease the RF power as long as the vacuum remains lower than the threshold. Once the vacuum is correct, RF power is increased.

To perform the RF power ramps, we start with a low RF pulse repetition rate of 1 Hz which is increased in steps. We define the following sequence:

- Conditioning in travelling wave at 1 Hz
- Conditioning in travelling wave at 14 Hz
- Conditioning in standing wave at 1 Hz
- Conditioning in standing wave at 2 Hz, 4 Hz, 8Hz
- Conditioning in standing wave at 14 Hz.

For each configuration, we change the pulse width (from short pulse widths (≈50 µs) to 3.6 ms). For the standing wave, two positions of the short circuit are defined: the first one gives a maximum of electric field close to the window ceramic. The second position allows a minimum of electric field at ceramic level. The automated handling of all the conditioning sequences, the interlocks and the data recording are controlled with EPICS.

Besides, we are improving our infrastructure with the presence of a second klystron to perform the conditioning of two pairs of couplers in parallel.

CONDITIONING OF COUPLERS

For the pre-series, six medium-beta couplers have been conditioned. Each pair of couplers followed the preparation described previously. The duration of the RF conditioning for the three pairs turned out to be respectively 167 hours, 86 hours and 233 hours. These durations are very

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variable depending on time needed to pass the multipactor barriers as well as on the exact chaining of the conditioning.

To validate the conditioning, we defined criteria on some specific RF power ramps: travelling wave (14 Hz, 3.6 ms, 1.1 MW max followed by a power plateau at 1.1 MW for 1 hour), standing wave (14 Hz, 500 µs, 1.1 MW max) for the 2 positions of the short circuit, standing wave (14 Hz, 3.6 ms, 300 kW max). The requirements are: maximal outgassing pressure lower than 2x10^{-8} mbar without electron activities and electrical arc phenomena on the full RF power range.

Figure 14 shows the beginning of the conditioning in travelling wave 1 Hz for different pulse widths. Lots of outgassing occur with some electron and arc activities.

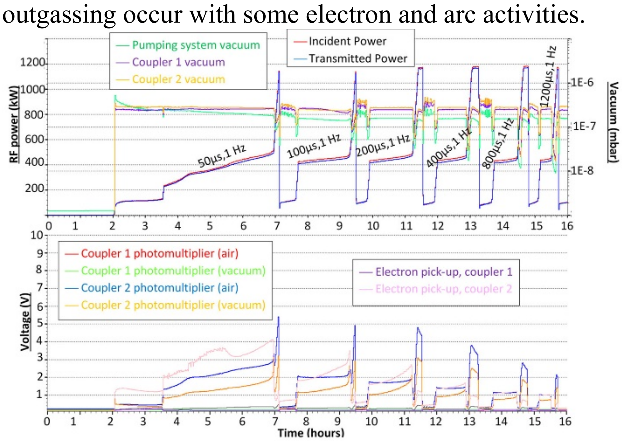

Figure 14: Travelling wave 1 Hz.

Concerning our acceptance criteria, the last ramp of the travelling wave (14 Hz, 3.6 ms) is performed without high outgassing and is consequently compliant, see Fig. 15. The external surface of the window reaches 35 °C max for an ambient temperature of 24 °C.

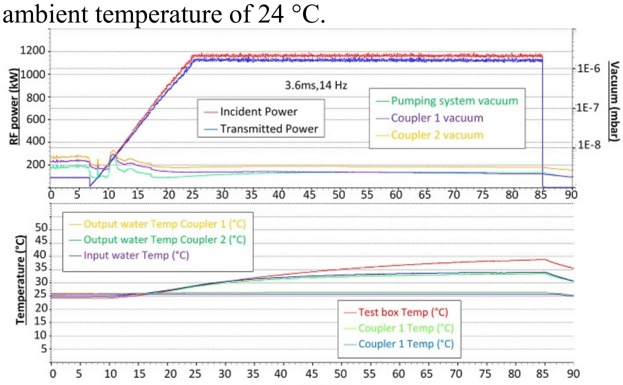

Figure 15: Travelling wave 14 Hz.

For the standing wave, the couplers are also compliant with our requirements (see Fig. 16 and Fig. 17 for the two positions of the short circuit). We can notice that a greater outgassing occurs for the short circuit position where the electric field is minimal close to the ceramic.

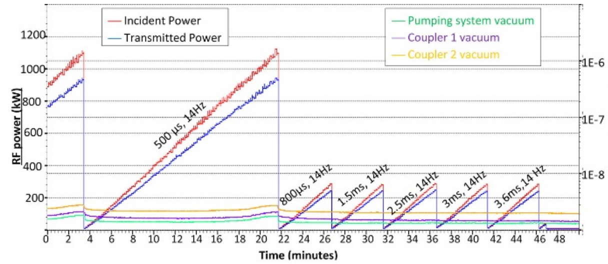

Figure 16: Standing wave 14 Hz (1st position of the short circuit).

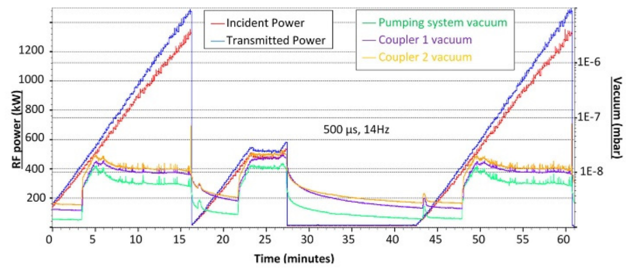

Figure 17: Standing wave 14 Hz (2nd position of the short circuit).

CONCLUSION

The successful conditioning of the six first pre-series couplers from the mass production allows validating the different manufacturing processes and launching the rest of the series couplers. Four pre-series couplers are currently assembled on the first series cryomodule [3]. At the moment, we are starting the conditioning of the next series couplers.

Besides, new wholly automatic pumping systems have been delivered with the possibility to record all the vacuum data and valve states.

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