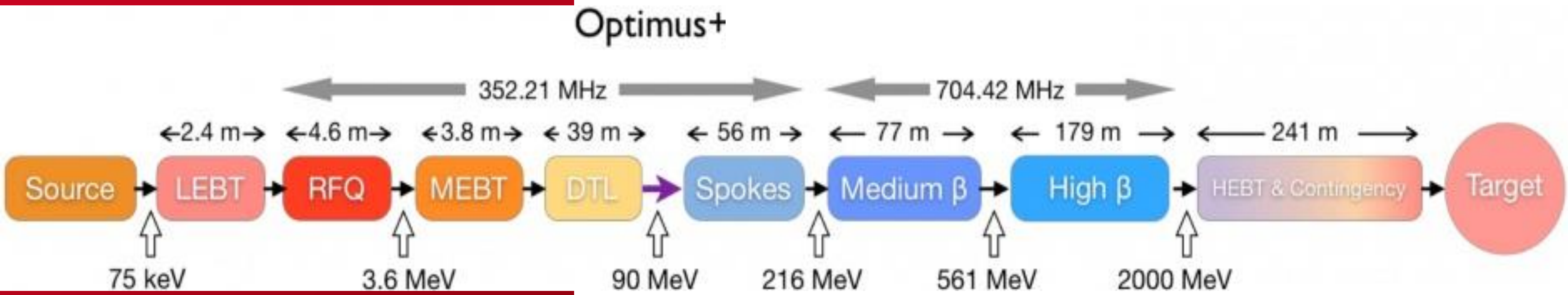
DE LA RECHERCHE À L'INDUSTRIE

TEST BENCH CONDITIONING OF THE ESS COUPLERS FOR ELLIPTICAL CAVITIES



TTC MEETING –Christian ARCAMBAL

4TH FEBRUARY 2020

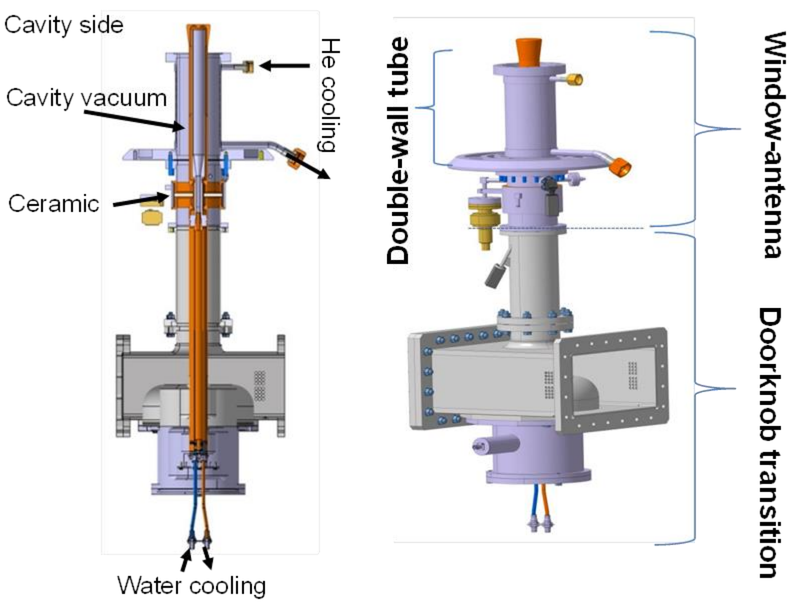
www.cea.fr

OVERVIEW OF THE ESS COUPLER

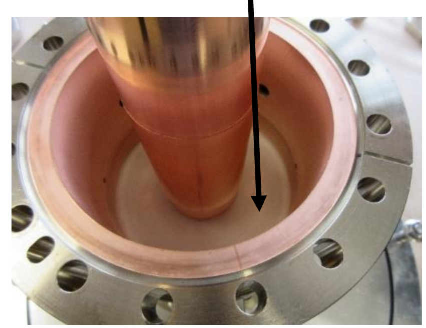
- **120** ESS couplers for elliptical cavities (36 medium beta (MB) whose 6 pre-series couplers + 84 high beta (HB) couplers).
- Three main parts: a **single window** with its antenna, a **double-wall tube**, a **doorknob transition**.
- Window-antenna and doorknob transitions common to MB and HB cavities. Double-wall tube slightly different between the 2 kinds of cavities: only the tube length is modified
- Cooling circuits:
  - Inner conductor: **water cooling**
  - Ceramic of the window: **natural air convection**
  - Double-wall tube: **Helium cooling**
- **Copper coating** and **TiN coating.**

Technical specifications

RF frequency	704.42MHz
Repetition frequency	14 Hz
Incident RF power	1.1 MW (peak)
RF pulse width in full reflection (all phases)	500 µs
RF pulse width in travelling waves	3.6 ms
Voltage withstand (voltage between internal conductor and external conductor)	±10 kV

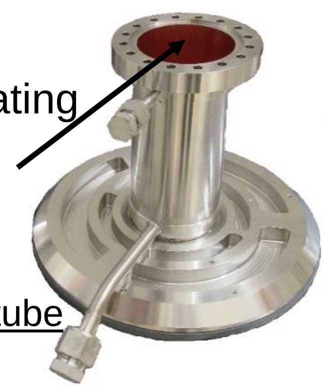


TiN coating (10nm)



Window

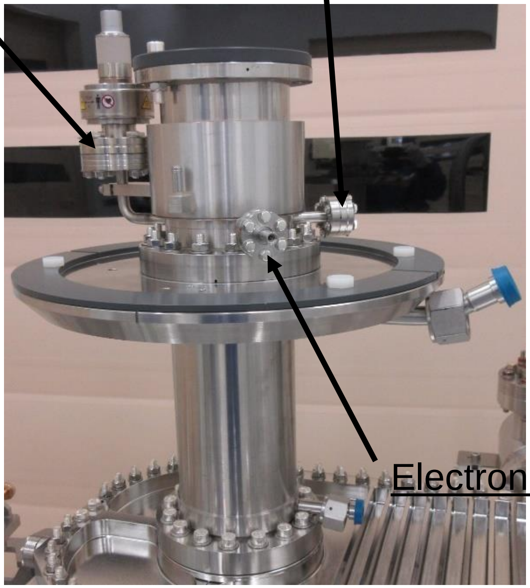
Copper coating (10µm)

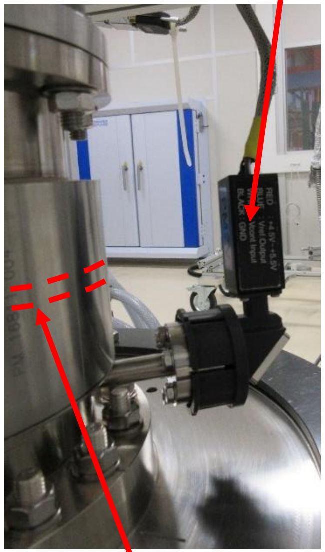


Double-wall tube

DIAGNOSTIC COMPONENTS

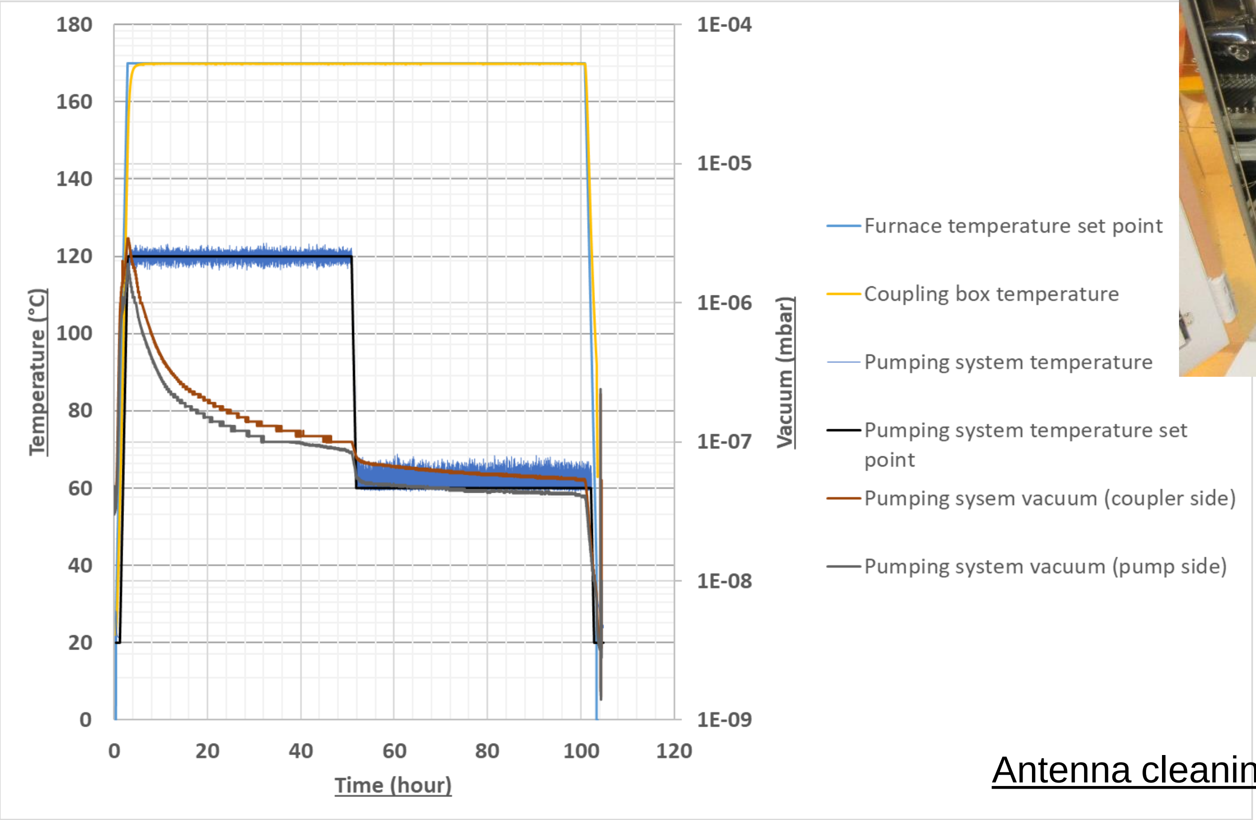
- Control instruments on the ESS couplers:
  - Vacuum gauge (IKR070 from Pfeiffer)
  - Window for photomultiplier (model H10721-110 from HAMAMATSU) (ceramic on the vacuum side)
  - Photomultiplier on the doorknob transition (ceramic on the air side)
  - Electron pick-up (for multipactor + RF coupling)
- Control instruments on the coupling box and pumping system:
  - Window for photomultiplier on the coupling box
  - Vacuum gauges on the pumping system



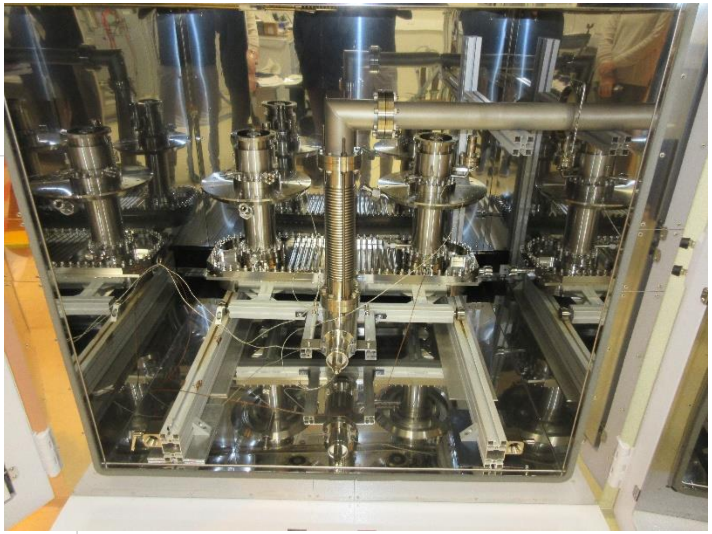


OPERATIONS BEFORE RF CONDITIONING

- Cleaning of the components:
  - Ultrasonic bath for double-wall tubes (Tickopur R33 detergent)
  - Manual cleaning for window (absolute ethanol, antenna cleaned with RBS T310)
- Assembly in a ISO5 cleanroom
- Baking in an oven (couplers 170°C for 4-5 days, pumping system 120°C then 60°C)



Baking (temperature and vacuum)



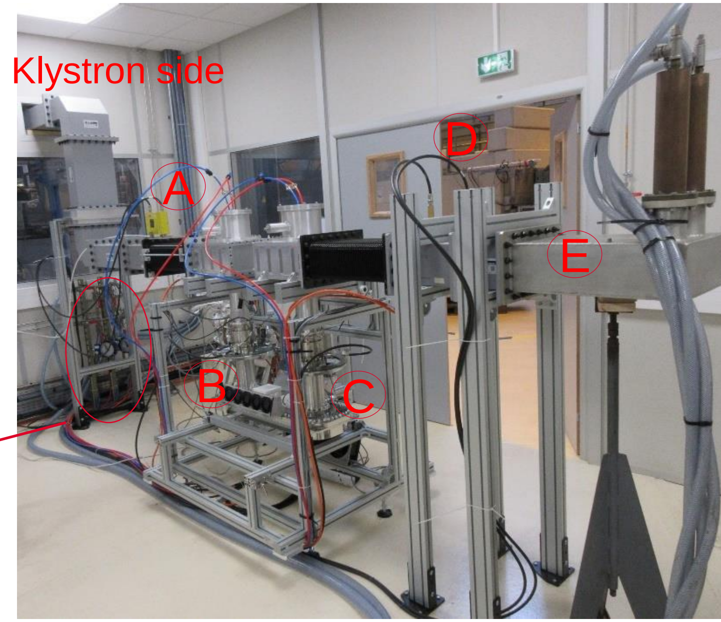
Couplers in the oven

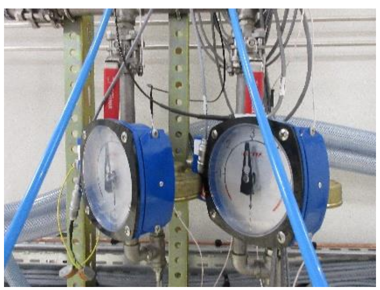
Antenna cleaning

Double-wall cleaning

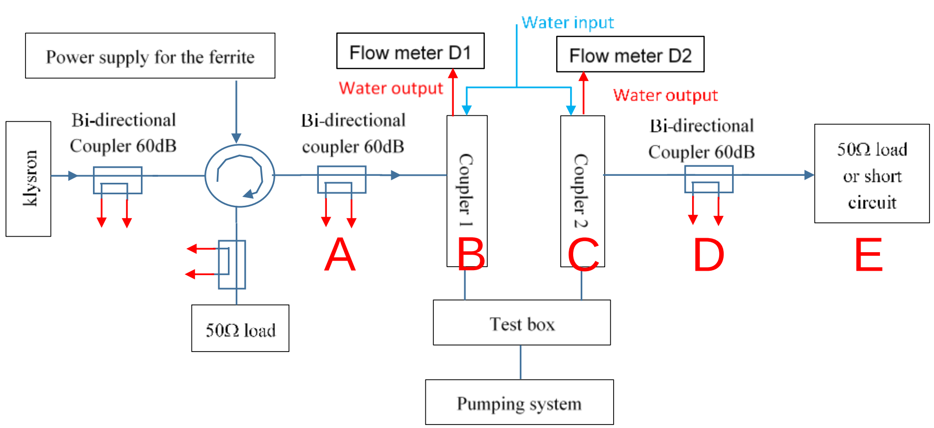
CONDITIONING TEST BENCH: MEASURED SIGNALS

- **Vacuum**: couplers and pumping system
- **RF power (incident & reverse)**: output of the klystron, input of the couplers, output of the couplers, image of the power in the coupler with the electron pick-up
- **Electrical arcs**: 2 photomultipliers for each ceramic, 1 for the test box
- **Multipactor** :electron pick-up
- **Water**: flowmeter and temperature probes (input, output)
- **Couplers temperature**: probes put on the window and on the box





Water flowmeter



Photomultiplier on the coupling box

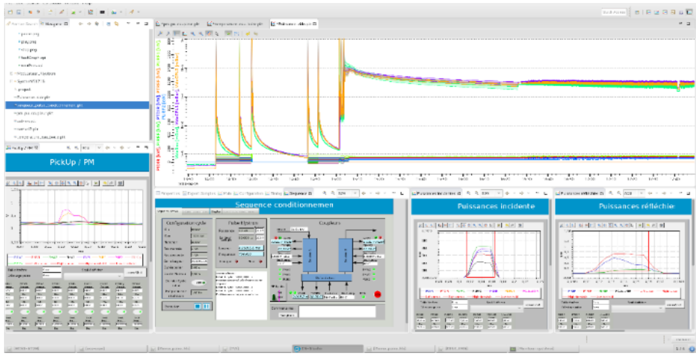
Temperature probe

CONDITIONING SEQUENCES

- RF power ramps from around 10 kW to 1.1 MW (pulse width from 50µs to 3.6ms), increase step by step (usually 1 kW per second). Increase or decrease of the power according to outgassing

- RF power switched off when
  - Outgassing with a vacuum level exceeding a hardware threshold defined at 1×10^{-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 electron pick-up).

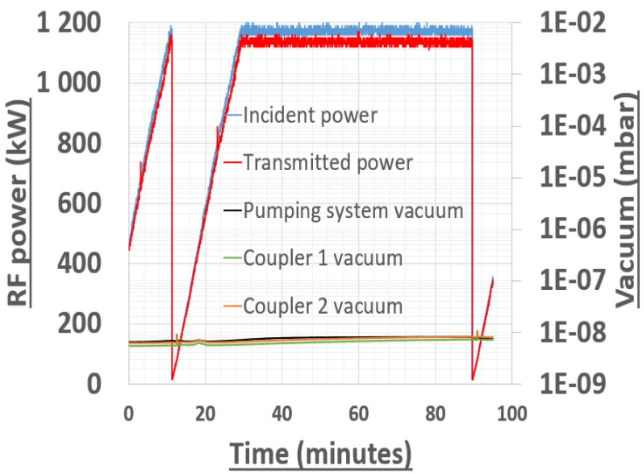
- Conditioning sequence:
  - Conditioning in travelling wave at 1 Hz
  - Conditioning in travelling wave at 14 Hz
  - Conditioning in standing wave at 1 Hz
  - Conditioning in standing wave at 2 Hz, 4 Hz, 8Hz
  - Conditioning in standing wave at 14 Hz.

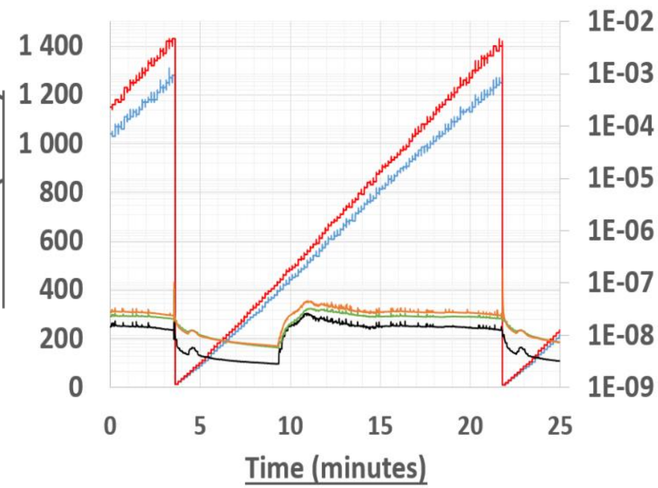


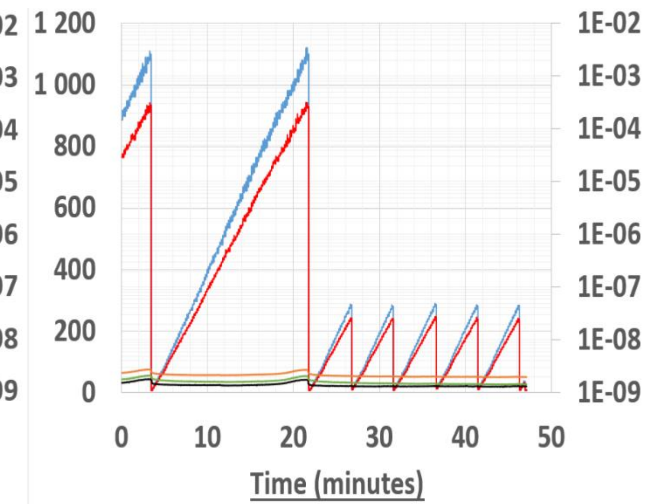
- The automated handling of all the conditioning sequences, the interlocks and the data recording are controlled with EPICS

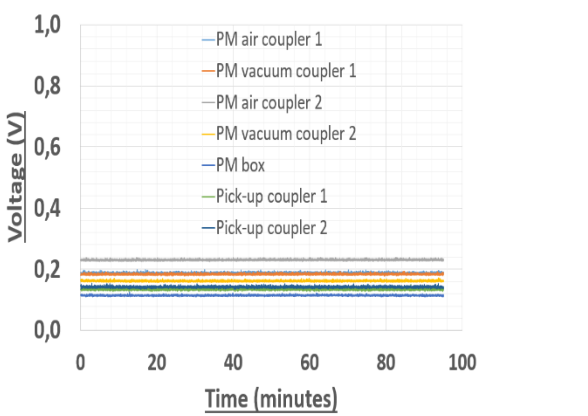
CONDITIONING OF PRE-SERIES COUPLERS

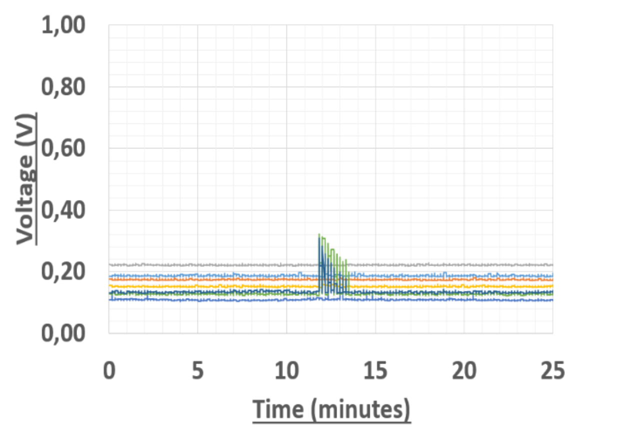
TW, 14Hz, 3.6ms | SW, 14Hz, 500µs, Min E | SW, 14Hz, 500µs-3.6ms, Max E

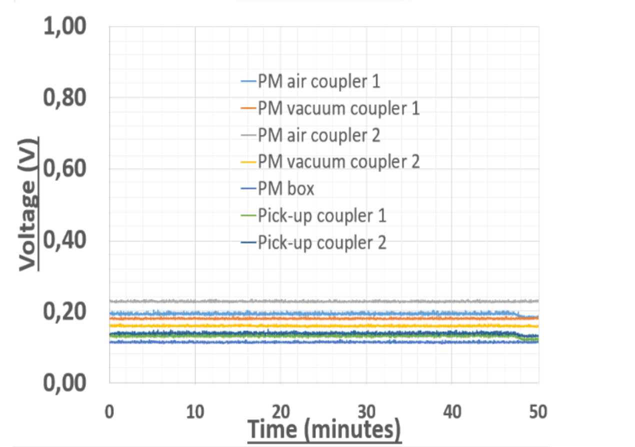










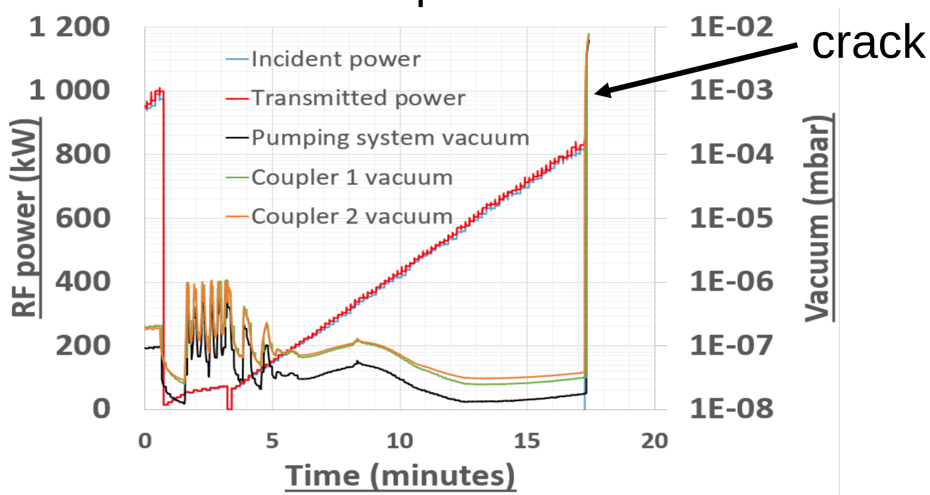


⇒Successful conditioning with minimum outgassing and electron activity

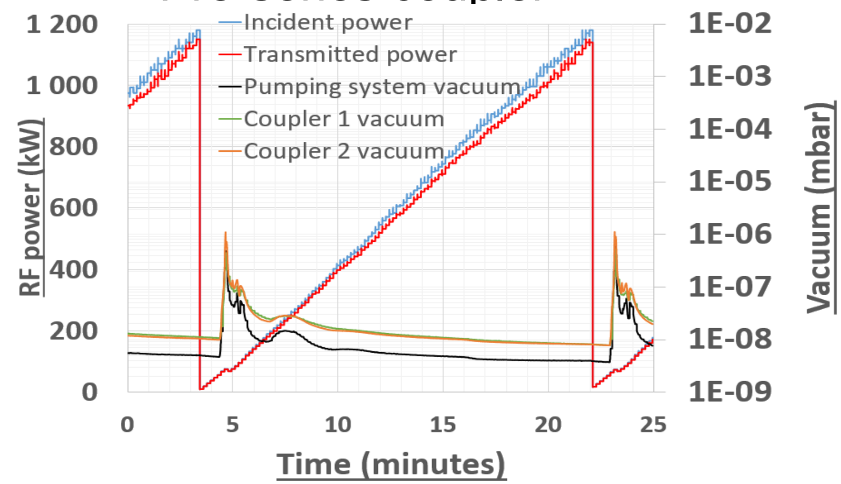
THE FIRST SERIES COUPLERS

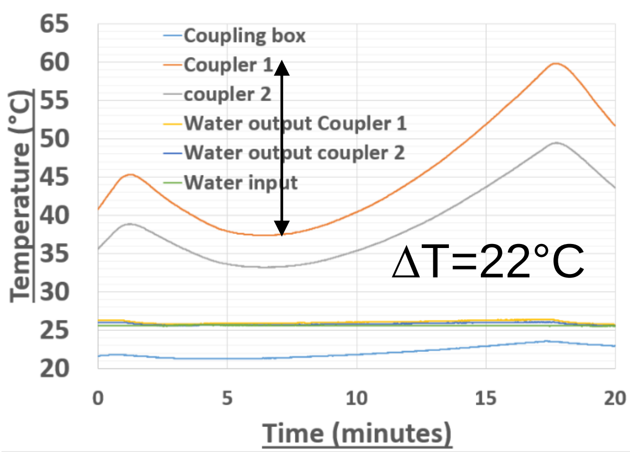
- During the conditioning of the first series couplers pair, a crack occurred on the ceramic (travelling wave, 14Hz, 2.5ms at 800kW) ⇒ loss of vacuum tightness
- Inspection of the other diagnostic signals ⇒ window temperature increased highly

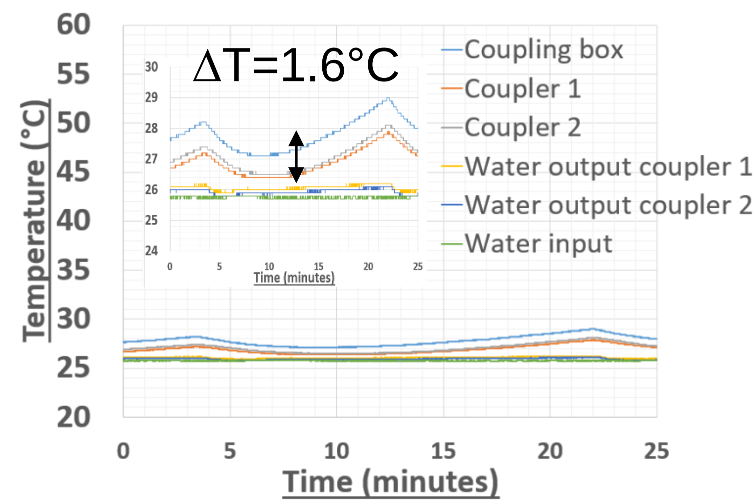
Series coupler



Pre-series coupler





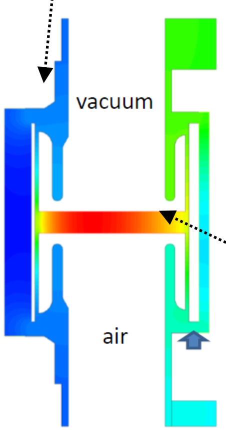


TEMPERATURE OF THE COUPLERS

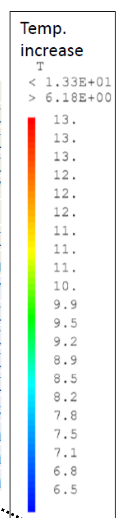
- We performed the conditioning with another pair, same temperature behavior as for the coupler with crack. Stop of the conditioning.
- Simulation performed to explain the temperature behavior of the couplers
  - With the nominal dielectric properties of the ceramic (nominal average power 55kW-3.6ms, 14Hz, 1MW peak), impossible to find the high temperature in spite of pessimistic heat transfer coefficients
  - Increase of dielectric losses (x10), average power 6kW obtained when we stop the conditioning ⇒ simulation similar to the temperature measurement
- Characterization of a ceramic without TiN (ε_r=9.47 and tan δ= 2.78 10^{-4}) and a ceramic with bad TiN (ε_r=9.44 and tan δ= 2.04 10^{-3}) with measurements at 1.8GHz in a resonant cavity

⇒ Losses increase by a factor 10 with the TiN coating

Inner conductor

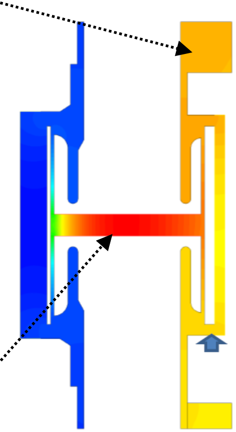


T_eau	T_air+6	
heau	500	W/m².K
h_air	5	W/m².K
h_air_canal	0.1	W/m².K
P RF (avg)	50000	W
tg delta ceram	**3.0E-04**	
lambda Cu	200	W/mK
RsCu 20°C	6.90E-03	Ohm
Pdiss_ceram	8.23	W
ΔT inner boundary	10.6	K
ΔT outer boundary	10.8	K
maximum ΔT	13.3	K
ΔT at sensor	8.84	K
Abs T at sensor	28.84	°C
Max VM Ceram	23.964	MPa
Max VM cuivre (int)	13.997	MPa
Max VM cuivre (ext)	23.744	MPa

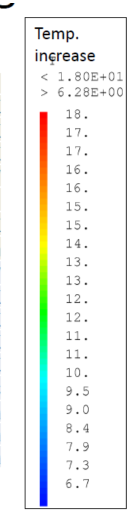


50kW average

Outer conductor



T_eau	T_air+6	
heau	500	W/m².K
h_air	5	W/m².K
h_air_canal	0.1	W/m².K
P RF (avg)	**6000**	W
tg delta ceram	**3.0E-03**	
lambda Cu	200	W/mK
RsCu 20°C	6.90E-03	Ohm
Pdiss_ceram	9.87	W
ΔT inner boundary	12.5	K
ΔT outer boundary	16.2	K
maximum ΔT	18	K
ΔT at sensor	14.6	K
Abs T at sensor	**34.6**	°C
Max VM Ceram	37.8	MPa
Max VM cuivre (int)	15.5	MPa
Max VM cuivre (ext)	38	MPa



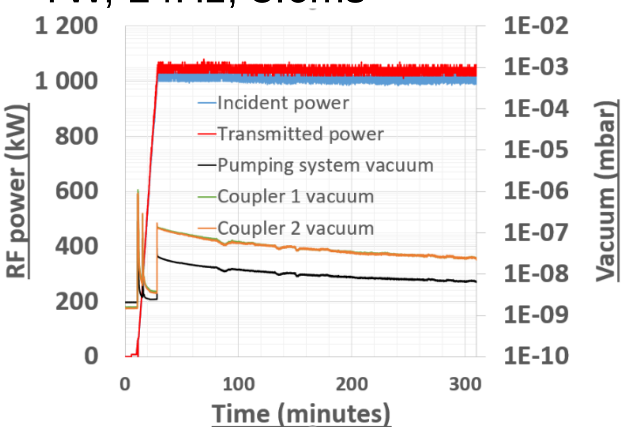
6kW average

ceramic

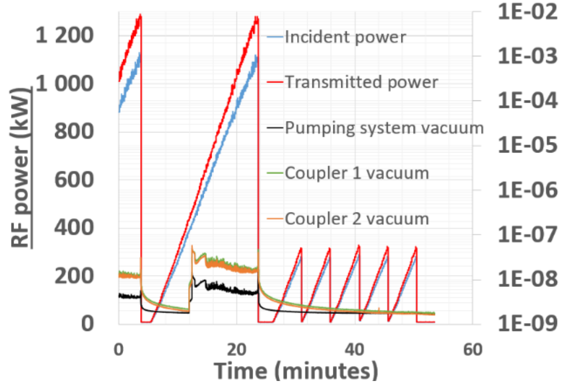
CONDITIONING OF A COUPLER WITHOUT TIN COATING

- To be sure that this temperature behavior comes (only) from a bad TiN coating, we conditioned a coupler without TiN coating (associated with a prototype coupler with a good TiN coating).

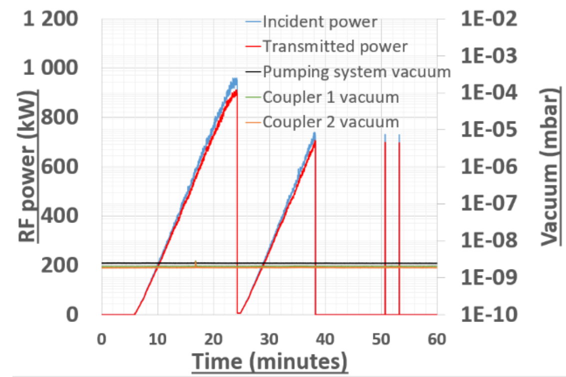
TW, 14Hz, 3.6ms

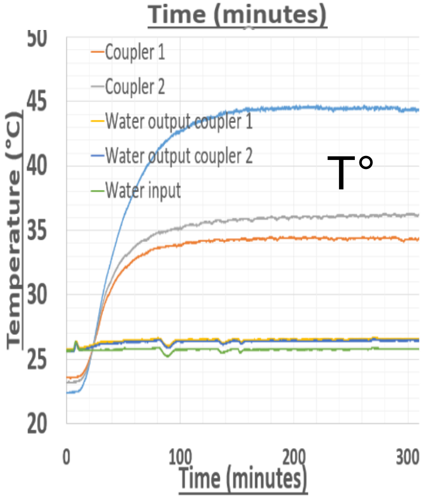


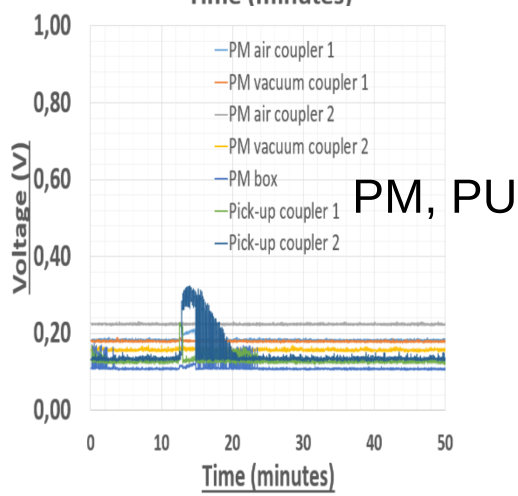
SW, 14Hz, 500µs-3.6ms, Min E

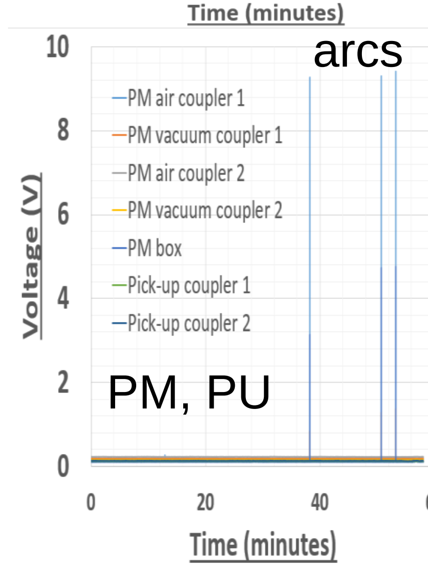


SW, 1Hz, 50µs, Max E









⇒Normal temperature behavior but conditioning stopped in SW (Max E) due to lots of electrical arcs

TIN VALIDATION TEST

- In the manufacturing process, the TiN coating is performed after brazing of the ceramic

- Currently, the TiN subcontractor doesn't succeed in performing the same TiN coating as for the pre-series. Work with another TiN subcontractor

- Tests performed before TiN coating of the window:
  - TiN coating on samples (silicon or vitreous carbon) put on a ceramic in a mock-up similar to the window
  - Thickness and stoichiometric measurements on the samples
  - TiN coating on a ceramic in the mock-up
  - Low level RF measurement on the ceramic in the mock-up (reflection and transmission coefficients)
  - Measurement of the resistance of the TiN coating with a multimeter

- Tests after TiN coating of the window (before welding of the antenna):
  - Low level RF measurement of the window
  - Measurement of the resistance of the TiN coating with a multimeter
  - Thickness measurement on samples put on the flange

CONCLUSION

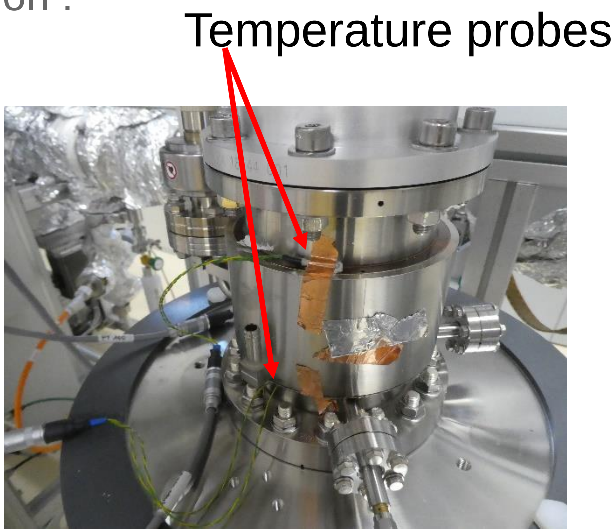
- For the mass production couplers, change of TiN subcontractor.
- The preliminary tests on samples and on coated windows seem to be correct
- **The next windows with the new TiN coating will be conditioned at CEA in February-March**

- In terms of conditioning:
  - The RF power ramp is managed with the vacuum on the coupler
  - We add a criterion on the window temperature in order to switch off the RF power when the temperature is too high
  - We add supplementary temperature probes around the ceramic
  - RF power is switched off with specific phenomena on :

    - Vacuum
    - Electrical arcs
    - Multipactor
    - Coupler temperature
    - Water flow
    - Electric arcs on the air side

    (for these 3 last phenomena, the operator has to reset the defaults)

    ⇒ **Lots of criteria to follow the conditioning**



THANK YOU FOR YOUR ATTENTION

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