RF Conditioning Strategy during HL-LHC

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International Review of the Crab Cavity system design and production plan for the HL-LHC
19-21 June 2019
CERN

Preamble

Design problems and construction defaults of the couplers can be the cause of many physical phenomena when the coupler is placed under vacuum and crossed by the Radio Frequency

These phenomena can be damaging for delicate parts of couplers such as ceramic windows providing barrier between the vacuum cavity and the atmospheric pressure

The function of the couplers can be guaranteed only after a RF conditioning, consisting in the **gradual adaptation** of the coupler to withstand electromagnetic fields created by the passage of the RF power

It reduces the violence of these phenomena and **allows to identify some couplers with construction problems**

The conditioning allows the **gradual reduction** of these phenomena by a **controlled increase of the power**, it must be **SAFE and SWIFT**

Processing of the couplers consist in applying RF power slowly increasing the power level to ensure that

- All multipacting levels have been processed
- Outgassing of all surfaces and ceramic feedthroughs is completed
- Ensure that all parts operate as expected at any power level

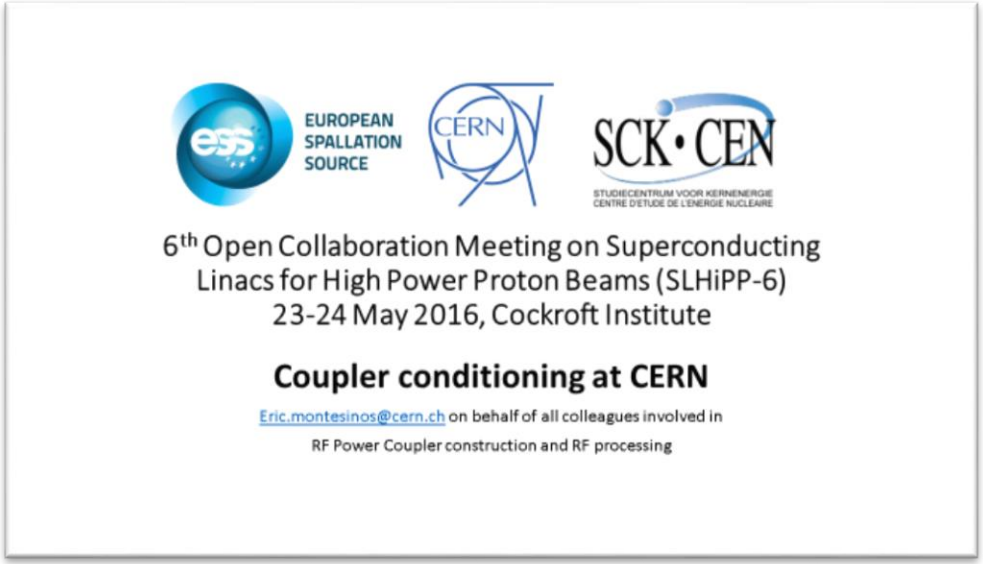
RF Processing method

The RF process is the one successfully experienced since 1998 with the SPS FPC

- Always start with short pulses
- Increase the power level under vacuum control
- Repeat until CW

It is the same process and the same electronics we already deployed all over the world

- CERN, SOLEIL, ESRF, APS, BNL, LAL, KEK
- Always a long process and we always have to be very cautious



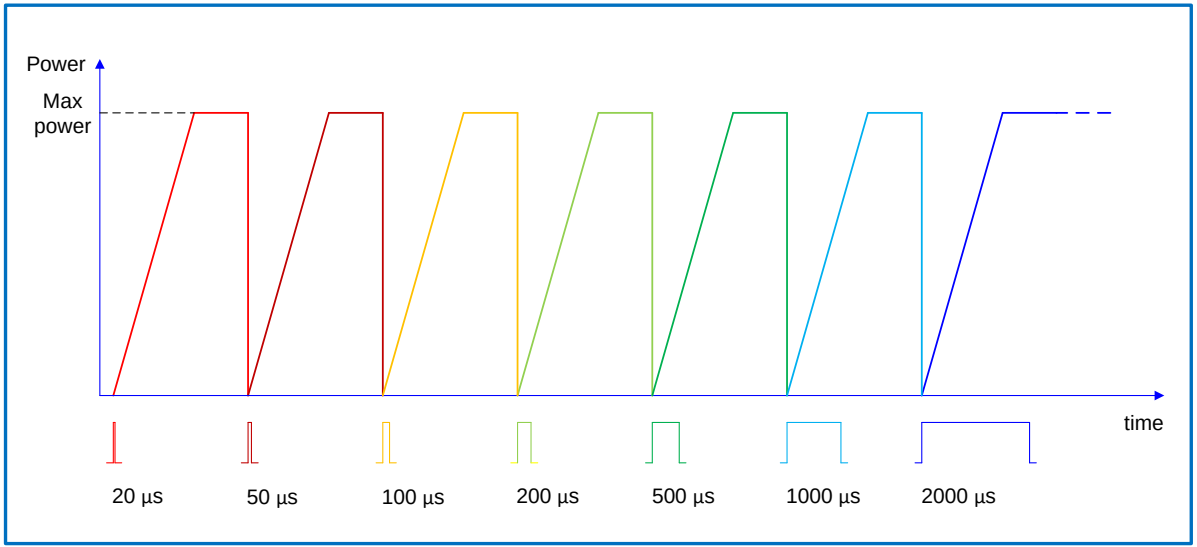
Please have a look at the SLHIPP-6 meeting
23-24 May 2016 at Cockcroft Institute
https://indico.esss.lu.se/event/528/session/2/contribution/15

RF Processing method

In order to be safe, we first ramp RF power with very short pulses from zero to full power

We then restart with longer pulses, again from zero to full power

We repeat the process until maximum pulse duration, that could be CW



Process with a minimum energy given to the sensitive components

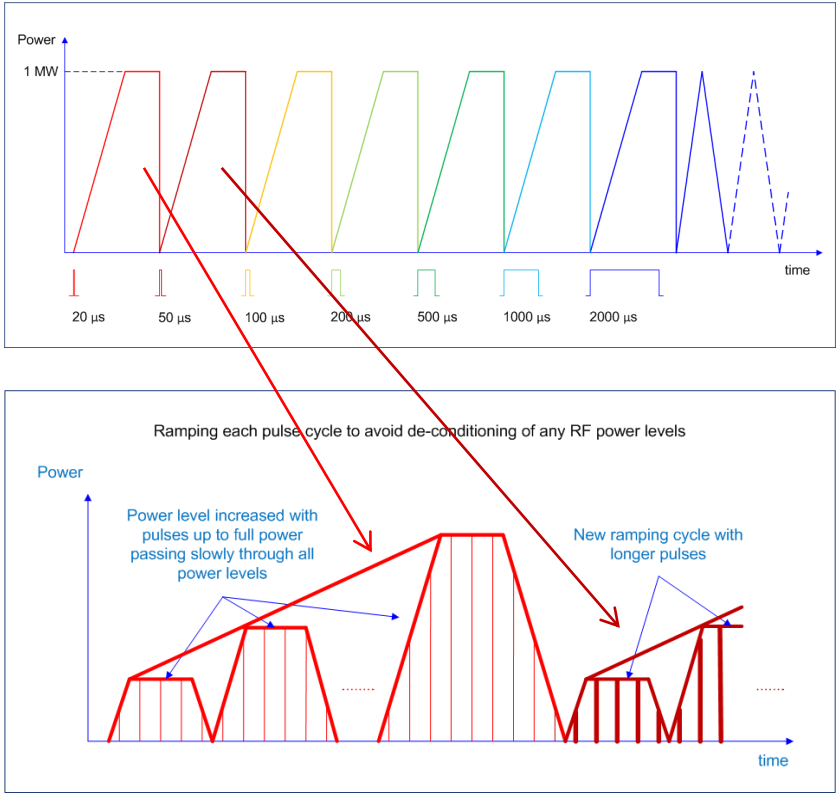
RF Processing method

What we also noticed is that making a ‘straight ramping’ could be dangerous

Indeed, a higher power level can ‘de-condition’ a lower power level previously processed

So inside one envelope, we ramp up and we ramp down to guaranty that ALL power levels have been processed with the shorter pulses

This process ensures that the lowest energy is deposited into an arc if it should occur

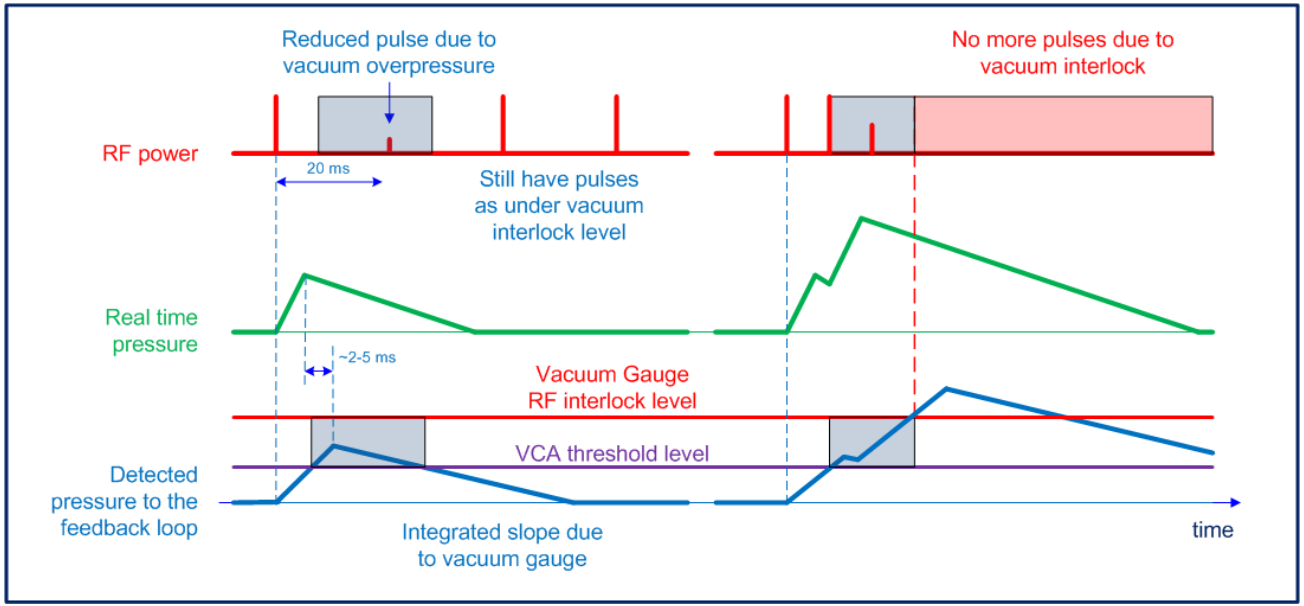


Always ramping the power level up and down to ensure that ALL power levels have been processed with the shorter pulses, i.e. minimum energy

RF Processing method

It is important to keep the repetition rate low enough to allow enough time to the vacuum gauge to detect the pressure rise

This allows not to stop the system, only few pulses are missed



Pulsing at a rate that allows the vacuum gauge to react speed-up the process as almost never stopping it

RF Processing method

In TW mode, with the test bench connected to a matched load, there will be no reflection

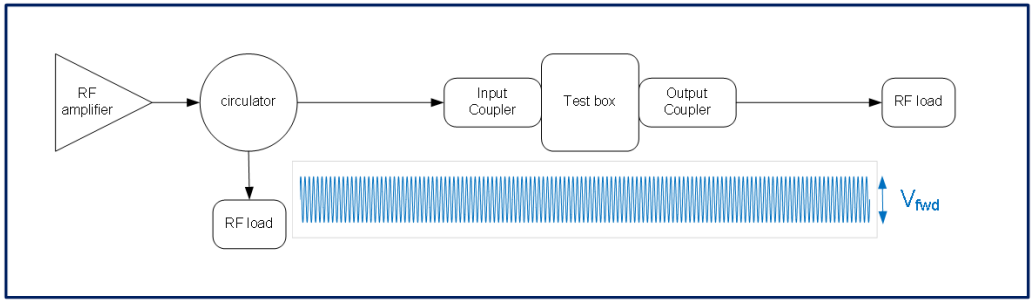
If the power source allows it, the couplers should be tested up to 1.5 their nominal operating value

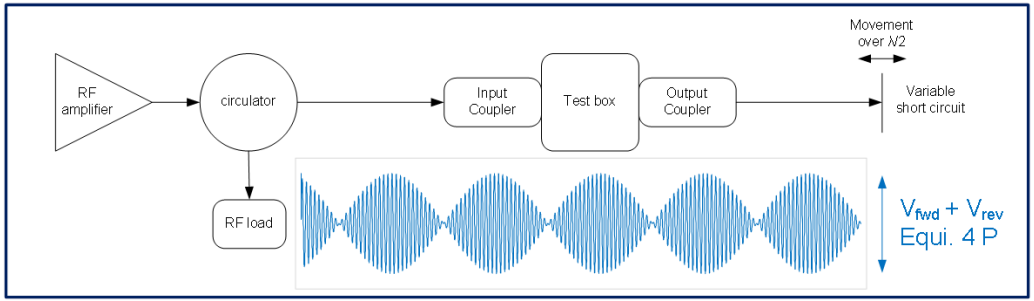
In SW mode, the test bench is connected to a variable short circuit that will be moved over λ/2

At every λ/4 + λ/2 from the short-circuit plane, there will be twice the voltage, equivalent to 4 times the power

This allows to qualify the couplers at any phase

This is required as when an arc or equivalent will occur, it will move towards the signal source, the amplifier, applying the same kind of voltage all along the transmission lines and the couplers





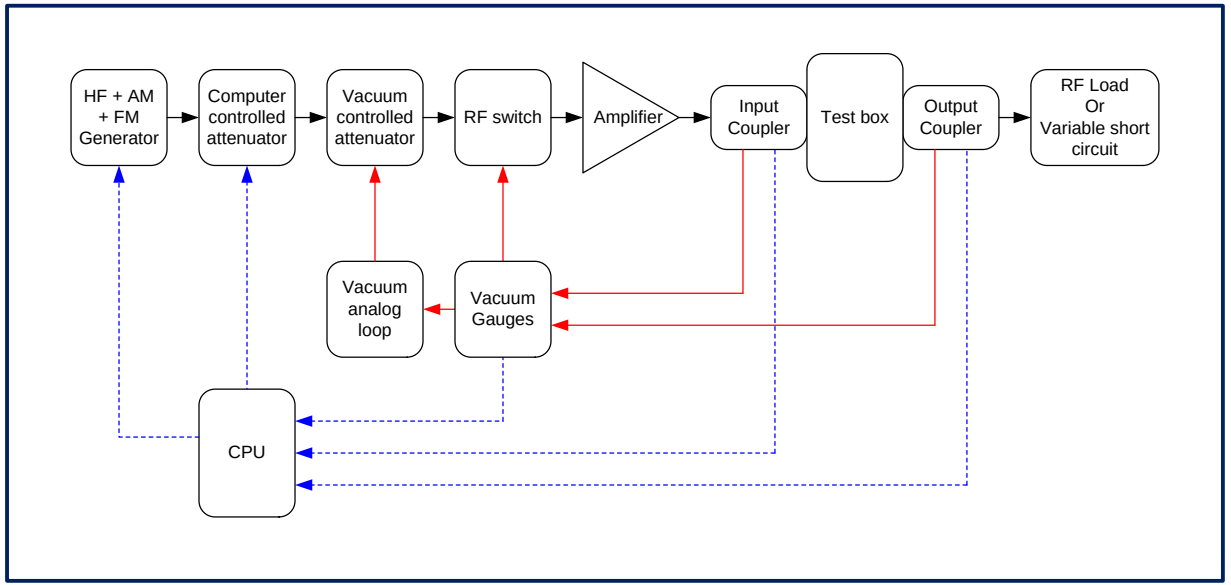
Both TW and SW are needed to fully qualify the devices as close as possible to operation

RF Processing method

In order to speed-up the process, we automated it

In addition to a first fast loop, a second loop, computer controlled, is also monitoring the vacuum pressure, and also acts in case of outgassing

Its main task is to safely increase the RF power level, being as quick as possible

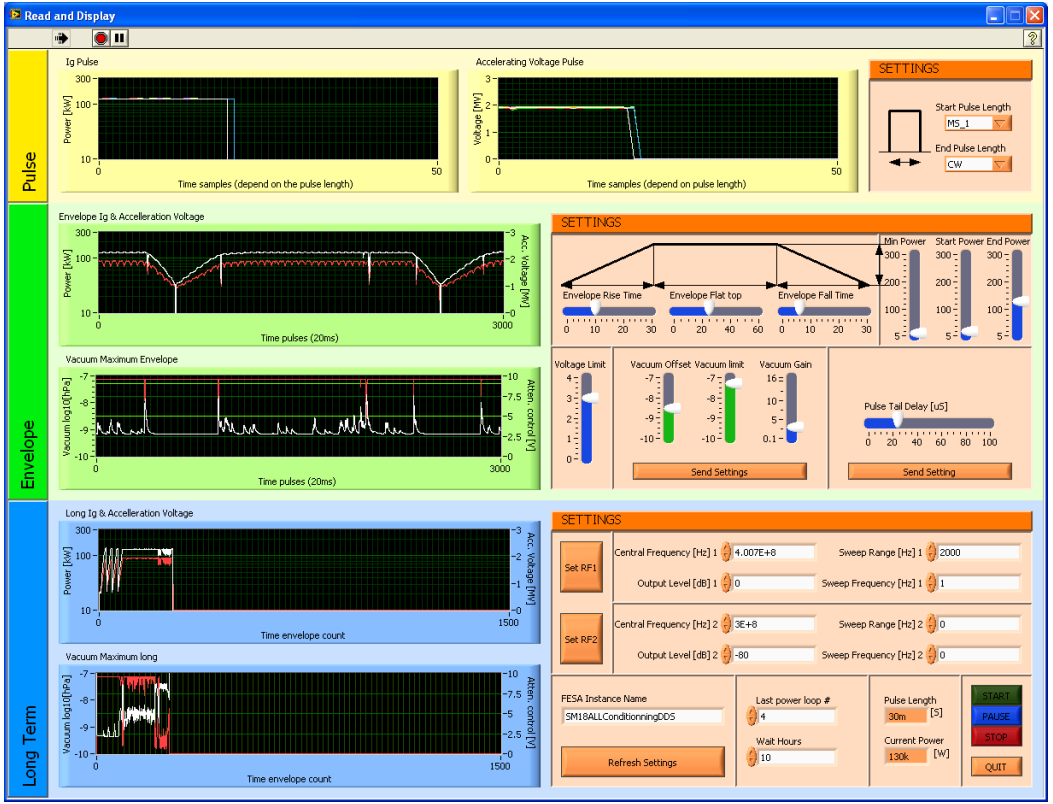


A dedicated system has been built for LHC FPC including all these functionalities and many additional ones

RF Processing method

GUI is designed to help the operators to apply the dedicated process for the given FPC

This example is the GUI developed for the LHC FPC

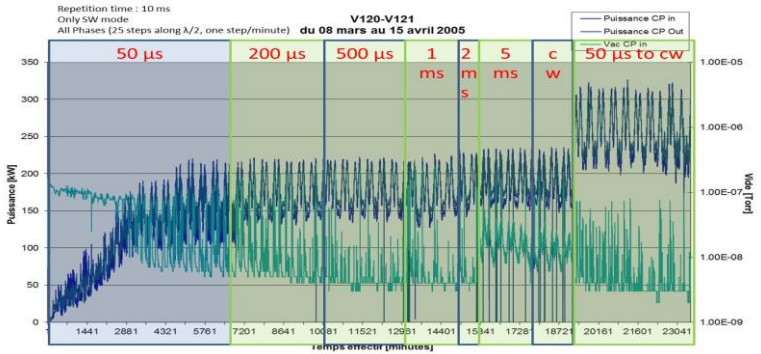


World Wide FPC meeting #5

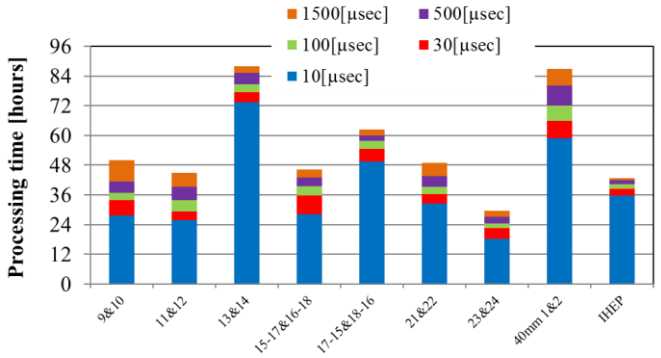
CERN	CERN	Eric Montesinos
KEK	KEK	Eiji Kako
DESY	DESY	Denis Kostin
KEK	KEK	Yasuchika Yamamoto
RIKEN	RIKEN	Kazutaka Ozeki
IHEP	IHEP	Tongming Huang
LAL	LAL	Walid Kaabi
IPNO	IPNO	Emmanouil Rampoux
BNL	BNL	Wencan Xu
IBS	IBS	Ilkyoung Shin
CEA	CEA	Guillaume Devanz
Cornell	Cornell	Vadim Veshcherevich
JLAB	JLAB	Mircea Stirbet
ORNL	ORNL	Yoon Kang
FNAL	FNAL	Sergey Kazakov
SLAC	SLAC	Chris Adolphsen
HZB	HZB	Emmy Sharples
IMP	IMP	Tiancai Jiang

RF Processing method

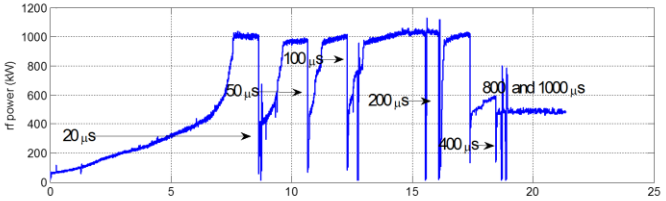
Please keep in mind that short pulses is always the most demanding step



First RF processing of LHC couplers



Summary of STF-2 FPC processing
Courtesy of Y. Yamamoto, A. Yamamoto, T. Matsumoto, E. Kako (KEK)



LCLS-II Couplers processing
courtesy of C. Adolphsen (SLAC)

Experience from the SPS

First assembly in clean room on test box

Bake out

RF process of two couplers face to face

Stored on test box RF processed under vacuum

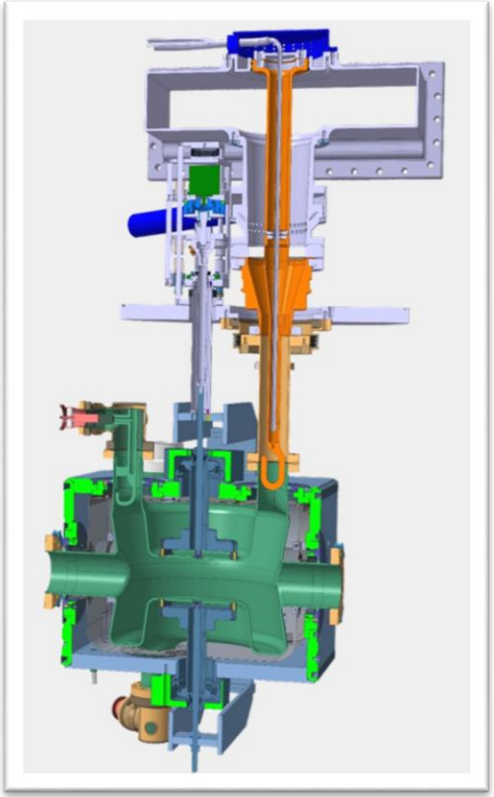
Assembly onto Crab cavity in clean room

RF process in SM18 at low power (1 kW)

Transport under vacuum to the accelerator

First RF process in-situ

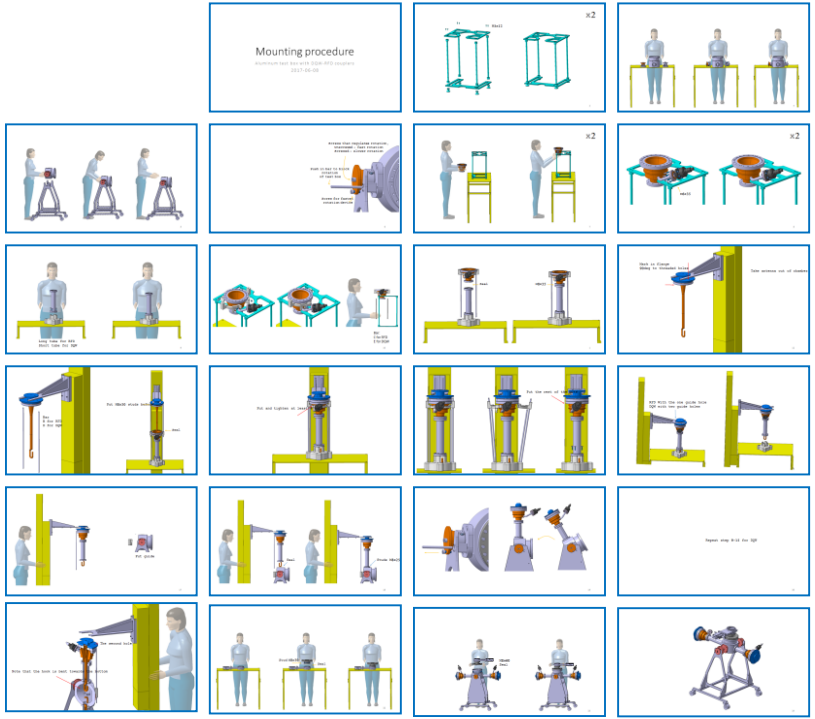
RF process after thermal cycle



This is a long process, with several RF processing before we can have the Couplers operating in a machine

FPC test box

As Crab is with high gradient, we needed to take care of the assembly of the FPC in clean room from the first day, including the first step, the assembly on the test box



FPC test box

During the assembly in clean room, we learnt a lot on many details, and we now have an improved process and the right tooling

FPC tests

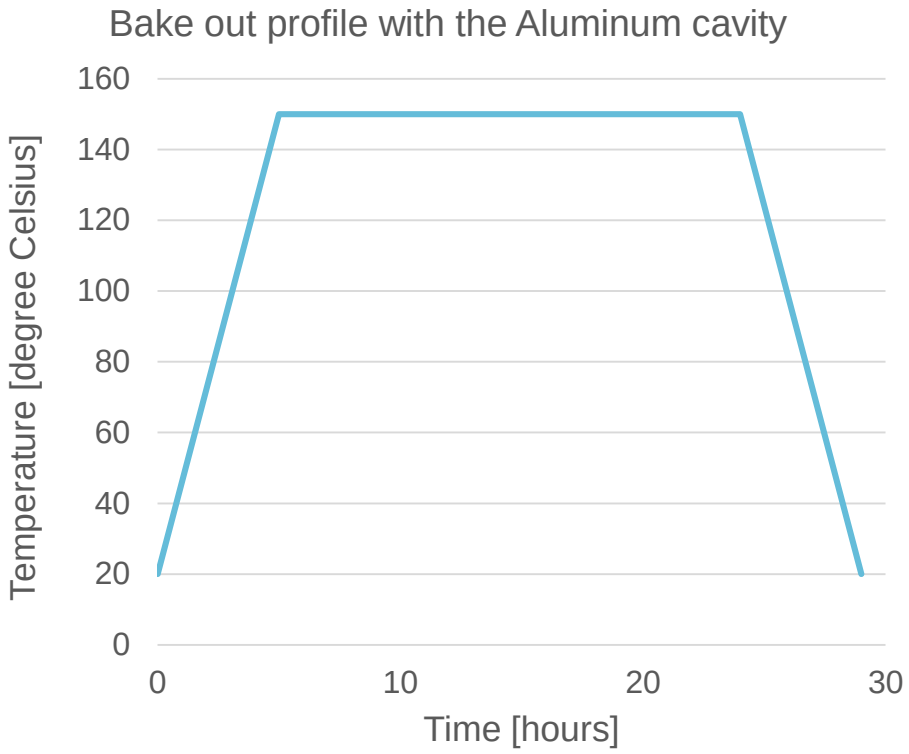
Following the experience with all the couplers we built over the last decades, we learnt that a well done bake out process considerably help to speed up the RF processing time

The first bake out process is done on with the test box

FPC tests

With the aluminium test box, we had to define a safe cycle, so we bake out the two couplers with the following programme

- Up to 150 °C with 30 °C/h
- 18 hours at 150 °C
- Down to room temp with 30 °C/h



FPC tests

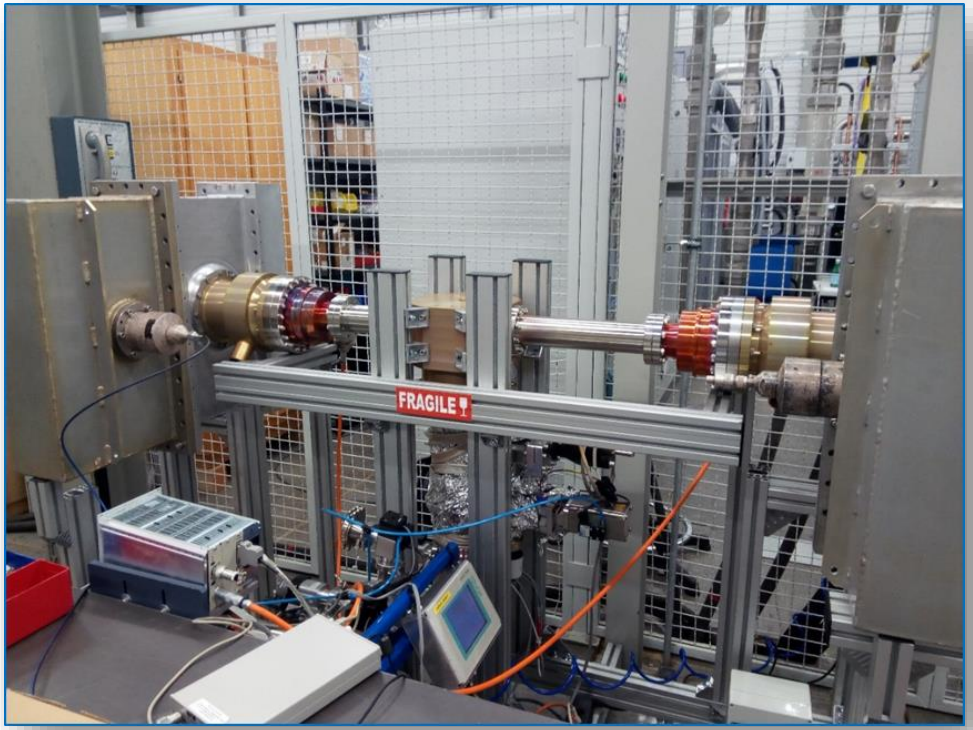
Two couplers face to face have been processed in TW

- 75 kW pulsed 10 ms @ 52.6 Hz
- 46 kW CW

We also processed them at the same values in SW, full reflection all phases

We processed

- 2 x DQW
- 1 x RFD & DQW



Assembly in clean room

Once the FPC have been RF processed, they are stored under vacuum until we assembled them in clean room

Processing in SM18

- Before installing the cryomodule in the SPS, we did some test in SM18
- As you can recognise on the picture, there were no waveguides
- Indeed, we did test with a small (1 kW) SSPA
- We knew that we would not have enough time for higher power levels
- It went as expected

Processing in SPS

After we install the cavities in SPS, processing of cavity #1 medium power was done

- RF conditioning started as usual in pulsed mode, with 20 µs pulses at 52.63 Hz
- Pulse length and RF power level have been increased up to 15 ms at 52.63 Hz and 10 kW with a FM of +/- 1 MHz around centre frequency
- We also completed 5 kW CW with a FM of +/- 500 kHz around centre frequency

Processing of cavity #2 was processed the same way

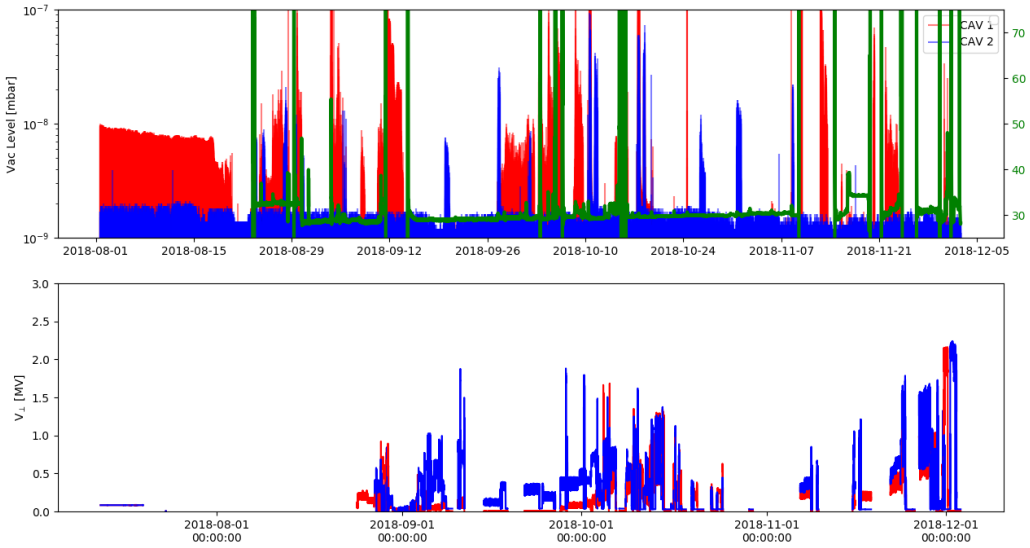
Processing in SPS

At one stage we were not able to increase the voltage, so it was time to do a thermal cycle in order to ‘clean’ them

We resume the RF processing, and all along the year, it was a balance between RF processing and doing MD

An outcome of this first year is that both cavities have a good ‘memory’

Resuming from previous reached levels was quite easy



What is expected for HL-LHC

We will apply almost the same process to ALL FPC

1. First assembly in clean room on test box (several additional test boxes to be built)
2. Bake out
3. RF process of two couplers face to face in BB3 (3 to 4 weeks all inclusive)
4. Storage on test box RF processed under vacuum
5. On request shipment to UK or Canada
6. Assembly onto Crab cavity in clean room
7. RF process in UK and Canada at medium power (15-20 kW CW)
8. Transport (under vacuum? tbd) to SM18
9. RF process in SM18 at medium power (15-20 kW CW)
10. Transport (under vacuum? tbd) to HL-LHC
11. First RF process in-situ (at warm ? +) at cold (40 kW CW)

RF process after every thermal cycle and during Technical Stops

What is expected for HL-LHC

We will have one 20 kW IOT amplifier or SSPA in SM18

We will have one 50 kW IOT amplifier or SSPA in BB3

We will provide one 20 kW SSPA to UK

We will provide one 20 kW SSPA to Canada

We will have 16 SSPA in the HL-LHC, and as soon as the services (EL, CV, VSC) will be available, we will process the cryomodules with automated systems

HOMC preparation

We also have in the pipeline to make a HOMC RF processing on a test box, in order to prepare them

(we bought a 1.5 kW 960 MHz SSA to make a trial)

HOMC have been specified for 1 kW CW !

Some Fundamental Power Couplers are doing less…

The overall process will then be similar as with the FPC

Conclusion

Thanks to SPS tests, we discovered that RF processing we applied for crab is similar than the one we applied to other FPC

All Crab cryomodules will be RF processed up to nominal fields before installation in the HL-LHC (as we did for Main RF systems)

Crab systems have a good memory of the RF processing even after a thermal cycle, this will ease operation in HL-LHC

As we will open beam vacuum for machine connection, the first RF processing will take several weeks with all services available (too early to set-up a schedule)

The following RF processing, after each Technical Stops, should be much shorter (access to the tunnel will be possible at the cost of RF stop)

Thanks to all colleagues involved with the FPC and conditioning systems (special thanks to Charles, Antoine, Seb, Mathieu Gaby, Max, BE-RF teams)

Thanks to Rama and Ofelia (WP4 leaders), to RF management, to BE management and to HL-LHC management for supporting us with this very exciting (and very challenging) project

We (BE-RF teams and all associated colleagues from many groups) are devoted to provide HL-LHC with reliable RF systems