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LIPAc SRF LINAC COUPLERS CONDITIONING

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Abstract

The LIPAc SRF Linac is a cryomodule with eight superconducting HWR cavities at 175 MHz powered by RF couplers capable of transmitting up to 200 kW in CW. To prepare the couplers for operation, cleaning and high power RF processing are needed. When performed, the couplers will be ready for integration in the cryomodule.

The Couplers Test Bench has been designed to perform the RF conditioning by pairs, providing good matching, low losses and the required UHV level. To preserve the cleanliness of the internal surfaces, after the test bench manufacturing, an ISO5 clean room has been used for the vacuum parts assembly. The size and number of particles was carefully controlled during the assembly process.

The RF conditioning was performed at the IFMIF-EVEDA RF Integration Facility using the Prototype RF Module in travelling wave and standing wave modes. The process started with short pulses at low power and finished when full power CW was reached. Vacuum, multipacting, arcs and matching were continuously monitored to control the process avoiding damages. An overview of the process applied to the prototypes and the RF conditioning results are presented in this paper.

SCOPE OF THE CONDITIONING

The conditioning main goal was the validation of the SRF Linac Power Coupler (PC) design [1] for LIPAc operation (up to 70kW CW) allowing the start of the eight units series manufacturing [2]. The two prototype PCs [3] were conditioned using the Prototype RF Module [4] and the Couplers Test Bench [5]. After the success of the conditioning, the prototype PCs will be used for the cryogenic tests with the prototype SRF Linac cavities and for a future validation of the design for IFMIF operation (up to 200kW CW).

PRE-CONDITIONING TASKS

Before starting the high power processing, some critical tasks had to be completed from mid 2013 in order to ensure a good conditioning of the prototypes.

ISO5 Clean Room Assembly

The PCs were assembled to the test-box in ISO5 environment, carefully monitoring the generated particles at each assembling step. A laser particle counter with 50 l/min airflow was used. The surfaces were considered clean if no more than six particles of 0.5µm (or bigger) were detected during 1 minute of dry nitrogen blowing. Some PVDF guiding shafts were used to perfectly center the coupler antenna into the test-box coupling cup. The crane holding the coupler was adjusted to use a very low descent rate (less than 1mm/s during final approach) and a multimeter was indicating if there was any physical contact that could scratch the surface of the antenna.

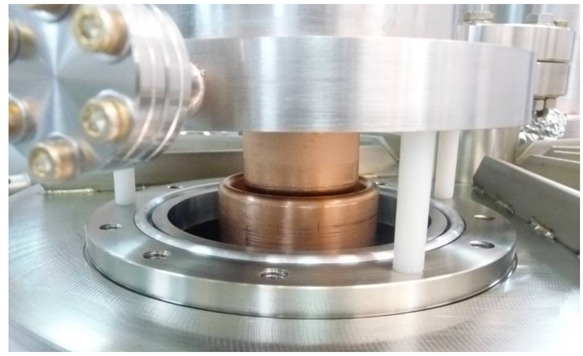

Figure 1: Coupler assembly to the Test-Box.

Vacuum Baking

The fully assembled vacuum chamber was baked to reach the target pressure before starting the RF processing. Around 100 hours of baking at 170ºC allowed reaching less than $5x10^{-9}$mbar after 50 hours at room temperature. A gradient of temperature was used to ease the vacuum pumping (160ºC on the test-box and 150ºC on the gate valve and turbopump inlet).

S-Parameters

After the installation of the airside matching transitions of the couplers (called “Tee” transitions), the test bench RF circuit was completed. In order to ensure a proper conditioning, the matching and the losses of the circuit were checked after vacuum pumping. The results showed a matching of 24.2dB and losses of 0.07dB at target vacuum (negligible difference with respect to atmospheric pressure; resonance not modified due to deformation).

Full Power Range Scanning

In order to predict the behavior of the PCs during RF conditioning and to have a first idea of the critical regions to be processed, a previous full power range scan was performed using single 7µs pulses, to avoid damaging the couplers with unexpected multipacting activity or arcs.

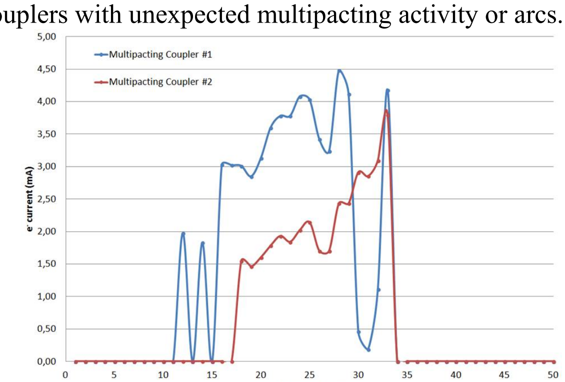

Figure 2: Multipacting barriers for both PC prototypes.

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Not a single arc occurred in the range up to 100kW and the currents measured on the electron pick-up antennas showed multipacting barriers (up to 5 mA e^- current) to be processed in the range between 10kW and 35kW (predicted by simulation between 14 and 32 kW [6]).

CONDITIONING PROCEDURE

Travelling Wave (TW)

In this mode the RF power was transmitted through the couplers/test-box assembly and dissipated in the full power load. The upstream coupler was connected to the RF source and the full power load was connected to the downstream coupler.

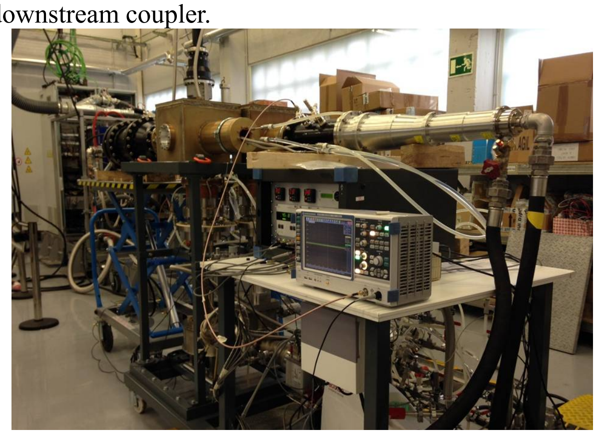

Figure 3: TW RF conditioning set-up.

The RF processing at 175MHz up to the hold level (100kW) started with pulses of 20µs at 2Hz repetition rate and low power (0.1kW). The power was progressively increased up to the hold level, at a rate of ΔP=0.1kW each Δt=5s (baseline values of ΔP and Δt) as long as the pressure and electron currents were under the thresholds. The power was maintained at the hold level during at least five minutes. After that, the RF power was cut off and the first duty cycle processing was completed.

The temperatures of the couplers and test-box were monitored although no interlocks were associated to them (manual shut down in case of high temperature).

The same scheme was repeated at 2Hz using the following pulse widths: 50µs, 100µs, 200µs, 500µs, 1ms, 2ms, 5ms, 10ms, 20ms, 50ms, 100ms, 200ms, 300ms and 400ms. Finally the power ramping was performed in CW.

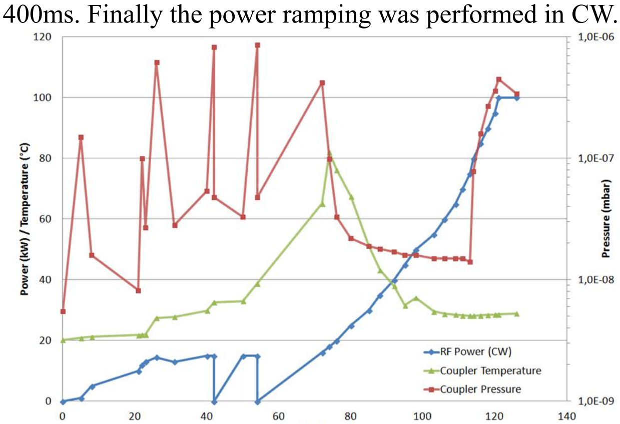

Figure 4: TW power ramping in CW (upstream coupler).

Standing Wave (SW)

In this mode the downstream load was changed by the sliding short-circuit and the full power load was then used at the circulator load port. This generated a total reflection, like the case of no beam injection, leading to a standing wave field distribution along the coupler with maximum local values that were twice higher than those of the TW configuration.

During the SW RF conditioning the field peak was moved step by step scanning all the coupler length by moving the short circuit (changing the reflected wave phase). For maximum location, the electron pick-up antenna was used for low power measurements that located the two short circuit positions generating the maximum electrical field on both ceramic windows. The SW RF conditioning started at these positions as they are the most critical areas for the couplers validation. Afterwards, the processing continued with six additional short circuit positions including two positions for which the electric field is maximized inside each Tee transition.

Conditioning Control

The fast interlock circuits responsible of the RF shutdown were fully calibrated before starting the conditioning, to avoid damaging the couplers.

The forward, reflected and load dissipated power was continuously monitored to observe the effect of the multipacting (MP) in the matching of the system and to measure the power dissipated in the couplers/test-box assembly. The matching was reduced up to 12dB when high MP currents were observed in the upstream coupler, generating some reflected RF going back to the circulator. Due to this effect, the downstream coupler behavior seemed delayed in terms of power, reacting in the same way but at higher power levels than the upstream one.

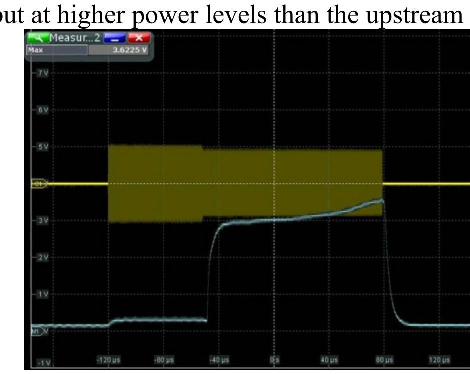

Figure 5: MP Mismatch – RF (yellow), MP current (blue).

When the vacuum "warning" threshold (software) was reached (baseline was 3×10^{-7}mbar; later doubled), power increase was stopped but continuing the process. When the vacuum recovered, the power continued increasing again. But if the "critical" threshold level (hardware) was reached (initially set at 6×10^{-7}mbar although after some sweeps it was increased up to 10^{-6}mbar due to the absence of arcs) an interlock was triggered to switch off the RF power in 30µs (gauge time response not included).

After an interlock event, the RF power restart was delayed at least five seconds, quickly increasing the

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power up to 90% of the previous power level reached (changing Δt to 1s). If the warning vacuum threshold was exceeded or the 90% was reached the processing continued with the baseline power ramping.

The MP electronic unit measured the e^- current with 0.1mA precision and the initial threshold value was set at 2mA (later increased to 5mA as the processing speed was dominated by the electron current instead of the vacuum behavior). If the threshold was triggered the RF was cut off in less than 30µs (full time response).

The arc detection unit sensitivity was set up to the maximum sensitivity (2lux) and the full response time for these events was measured below 10µs.

CONDITIONING RESULTS

Travelling Wave

The first low duty cycle sweeps allowed to learn a lot about the couplers behavior and to increase the threshold values to speed up the process. Pulsed conditioning narrowed the barrier (10kW to 18kW) and reduced the MP currents (from initial 5mA to less than 0.5mA). Finally 100kW CW in travelling wave was reached at the end of March 2014, without any noticeable MP current.

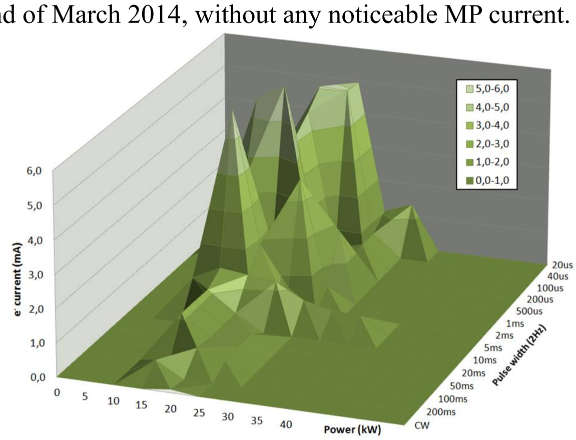

Figure 6: MP barriers processing for upstream coupler.

Some important vacuum bursts still persist between 12kW to 18kW; sometimes up to the limit (10^{-6}mbar) although the measured MP currents are zero (disappeared in the CW power sweep). Also, there are some vacuum bursts at 1kW (possibly due to MP in the test-box).

The temperatures of the outer conductor of the couplers and test-box were monitored during the high duty cycle phases and an increase of temperature in the upstream coupler was detected up to 82ºC (no external active air cooling) correlated with the vacuum bursts RF power levels. After additional sweeps in CW the vacuum bursts have been reduced but the temperature increase is still non-controlled but at a slower rate.

Standing Wave

Most of the RF processing effect was achieved during the TW conditioning, hence this mode was carried out with relative easiness. Neither MP currents nor big vacuum bursts were detected at any power level or shortcircuit position (the MP threshold was reduced to 0.5mA, due to the lack of e^- activity). This processing mode was completed during April 2014 reaching CW for all shortcircuit positions. Generally the first vacuum burst (up to $2x10^{-7}$mbar) occurred around 4kW and the test-box top cover starts to increase its temperature at power levels over 50kW requiring some active air cooling (even with fan the temperature reaches 80ºC requiring the system to stop for cool down). When the maximum E field is on the ceramic window, the vacuum increases in the 30kW to 70kW region but not exceeding 10^{-7}mbar at any point. When the maximum E field is on the coupler tee, the vacuum starts to react from 65kW increasing continuously its value up to 10^{-7}mbar at 100kW.

CONCLUSIONS

The TW conditioning has reduced gradually the pressure level and electron activity, demonstrating that the couplers are able to withstand up to 100kW CW. The e^- currents have been eliminated near the ceramic, the vacuum is $2x10^{-8}$mbar and the temperature is less than 35ºC for the LIPAc operation power range.

The SW conditioning has shown that there is no multipacting near the ceramic windows. Even with the maximum electric field located there, the vacuum is below 10^{-7}mbar in any condition and the couplers withstand full reflection indefinitely without any problem.

The conditioning process has shown that the PCs are performing as expected which fully validates the design of the power couplers for LIPAc operation.

ACKNOWLEDGMENTS

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