SARAF-Phase II: Test of the SRF Cavities with the First Cryomodule

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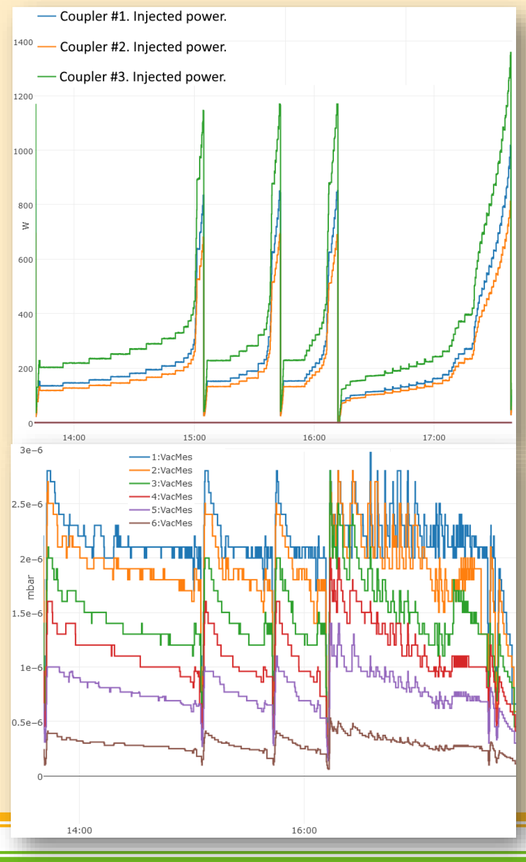
CEA is building a new accelerator for SARAF Phase II [1]. The SARAF Phase II Linac will consist in 4 cryomodules with HWR cavities at the frequency of 176 MHz. The low- and high-beta cavities are optimized to βopt=0.09 and βopt=0.18 respectively [2]. This poster focuses on the results with the cavities and their auxiliaries in the first cryomodule. This cryomodule contains 6 low-beta cavities.

RF conditioning

It took 6 days to condition the 6 couplers. During the conditioning, the pressure was maintained at 2.10^{-6} mbar. At the beginning of each iteration, a peak of pressure appears. Coupler #1 limited the conditioning time as it is the one that showed the higher pressure during the full conditioning process.
No electrical breakdown appeared during the test. But the pressure increased very fast up to 10^{-5} mbar during the very first iterations, without arcing.
Pumping is done through cavity #6 beam line. Pressure in cavity #1 to 5 was always lower than in cavity #6.
On the right: conditioning of couplers 1 to 3 from 100 to 800 ms pulses, at 1 Hz.



Qext

Qext was measured with VNA and with decay time.
Results vary by about 20% between both methods. VNA is the most accurate, as the decay time depends on the impedance of the amplifier.

Target was [7.4, 16.7] 10^5. All coupler antennas reached the target.

Cav #	1	2	3	4	5	6
Qext	According to VNA					
$\times 10^5$	14.9	13.6	13.0	13.8	15.5	15.3
Qext	According to decay time					
$\times 10^5$	12.0	11.2	10.8	14.0	17.1	14.4

Frequency tuning

Initial frequency

Measurement of the frequency shift (f – 176 MHz) with the VNA, before tuning:

Cavity	1	2	3	4	5	6
Shift kHz	68	56	31	47	108	64

After tuning

After tuning, all cavities were at 176 000 000 MHz ± 10 Hz. The stability of the helium bath was ± 5 mbar.
The target sensitivity to the helium bath was < 5 Hz/mbar. No req. for Lorentz detuning.
Sensitivity to helium bath:

Cavity	1	2	3	4	5	6
Hz/mbar	1.4	-0.5	1.7	0.6	1.7	2.9

Lorentz force detuning (@ 1 MV, $\beta = 0.091$).

Cavity	1	2	3	4	5	6
Hz/MV²	277	265	230	208	332	183

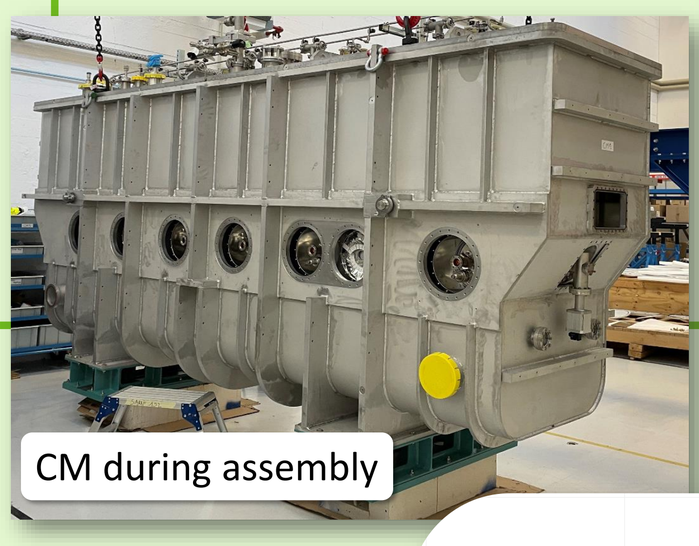
Cryogenic consumption

Target accelerating field

Cavities are designed to reach 1.09 MV @ $\boldsymbol{\beta = 0.091}$ / 176 MHz. (7.1 MV/m).
All cavities, except #6 reached the field at the first try.
Cav #6 was conditioned at 95% of the target during 100 min, and 90 min at 100% of the target. A reduction by a factor 10 on the X-ray emission was observed.

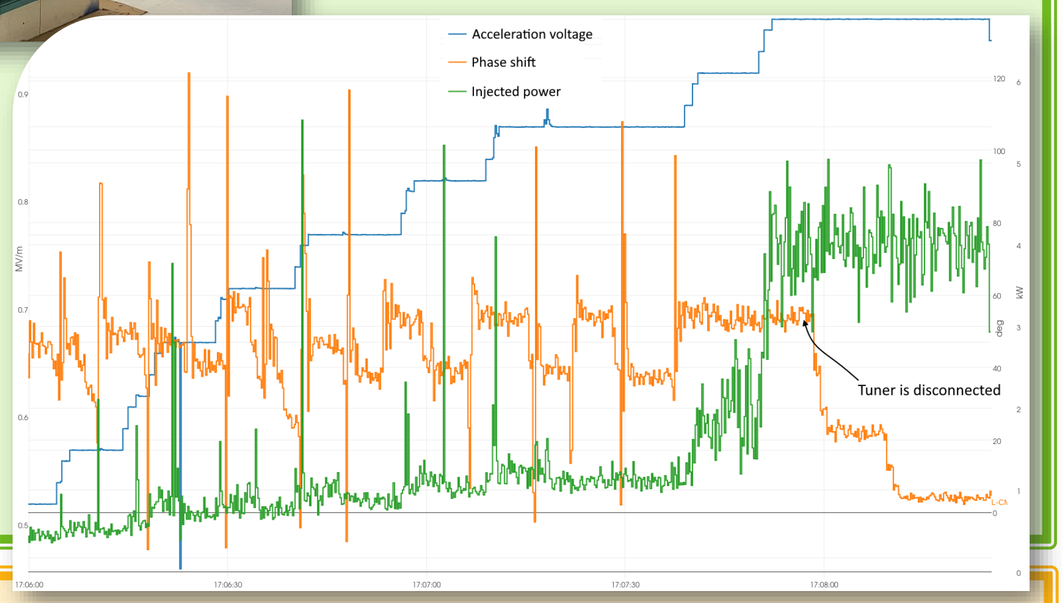
Cryogenic consumption

Measured with the helium gas flow, without, and with RF.
All cavities reached a cryogenic consumption of 5 W +/- 2 W, except cavity 6, 10 W +/- 2 W. Cavity #6 X-ray emission improved after cryogenic consumption test. Thus, it was certainly less than 10 W at the end of the tests.
The target was 10 W.



Operation mode

This test was the final test, with the LLRF [3] and the tuner. The test is done at 176 MHz exactly, with LLRF in closed-loop mode and tuner in phased-locked loop (PLL) mode.
All cavities reached the operating field, but high vibrations were observed when the tuner is activated by its PLL.
For cavity 5, vibrations were so huge that the tuner was deactivated at 90% of the field, and the field was reached without PLL on the tuner automate.
On the right: one of the tests with cavity 5. The phase is the one of the PLL, locked at 50° +/- 10°. The figure shows when the tuner was deactivated.



Despite some difficulties due to the vibrations of the tuner motors, all the requirements were successfully verified. Only one cavity required some conditioning to reach the target. The power consumption was compliant with the cryogenic requirements, even if the 6th cavity required a bit more than expected. The external quality factor of the couplers was compliant for all couplers.
The only difficulty was with the effect of the vibrations of the tuner motors on the cavities. Some new PLC parameters will be tested with the following cryomodules to try to reduce the vibrations.
After the qualification, the cryomodule was sent to SNRC, in Israel for tests with beam.

[1] N. Pichoff et al., “The SARAF-Linac Project 2019 Status”, IPAC’19, Melbourne, Australia (2019).
[2] G. Ferrand et al, “Designing a 176 MHz Superconducting Half-Wave Resonator for SARAF-Phase II - Studies and Results”,IEEE Trans. Applied. Superconductivity, vol. 32, no. 7, oct. 2022.
[3] J. Fernandez et al, “Status of the uTCA Digital LLRF design for SARAF Phase II”, ICALEPS21, on-line (2021).