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# RESULTS OF CEA TESTS OF SARAF COUPLERS PROTOTYPES

G. Ferrand†, Y. Baron, S. Bouaziz, C. Boulch, D. Chirpaz-Cerbat, R. Cubizolles, E. Fayette, F. Gohier, P. Guiho, S. Ladegaillerie, A. Lotode, Y. Lussignol, C. Madec, G. Monnereau, N. Pichoff, O. Piquet, C. Servouin
IRFU, CEA, Université Paris-Saclay, France

*Abstract*

CEA is committed to delivering a Medium Energy Beam Transfer line and a superconducting linac (SCL) for SARAF accelerator in order to accelerate 5 mA beam of either protons from 1.3 MeV to 35 MeV or deuterons from 2.6 MeV to 40 MeV. The SCL consists in 4 cryomodules. The first two cryomodules host 6 and 7 half-wave resonator (HWR) low beta cavities ($\beta$ = 0.09) at 176 MHz. The last two identical cryomodule will host 7 HWR high-beta cavities ($\beta$ = 0.18) at 176 MHz. The maximal required power to be transmitted to the beam is 11.4 kW for high-beta cavity couplers. This document presents the results of the coupler tests and conditioning.

## INTRODUCTION

CEA is building a new accelerator for SARAF Phase II [1]. A key element of the project is the superconducting linac at 40 MeV (deuterons) or 35 MeV (protons). The SARAF Phase II Linac will consist in 4 cryomodules with HWR cavities at the frequency of 176 MHz. The maximal beam current in the Linac will be 5 mA for maximal accelerating voltages of 1.0 MV and 2.3 MV for low and high betas respectively. For high-beta cavities, this means that RF power couplers will have to deliver at least 11.4 kW to the beam.

This document focuses on the results of the coupler tests with conditioning boxes. The tests of the coupler with cavity and tuner in a dedicated Equipped Cavity Test Stand (ECTS) are presented in [2].

## REQUIREMENTS

The same power coupler will be connected to low- and high-beta cavities. Consequently, power requirements for all couplers are defined by requirements for high-beta cavities couplers, i.e. 11.4 kW to be transmitted to the beams. Considering mismatching (couplers cannot be matched separately) and detuning, margins must be considered for the tests.

We calculated that, if power couplers can accept 18.5 kW during at least 6 hours in travelling wave, and 10 kW during a few minutes in full reflection mode, they will be able to accept 11.4 kW with a comfortable detuning and expected mismatch.

Moreover, the coupler desorption requirement is $5.10^{-6}$ mbar.l/s, in order to not degrade the performances of the cavities in operation.

## COUPLERS DESIGN AND MANUFACTURING

SARAF couplers consist in an antenna in copper, brazed to an alumina ceramic with TiN coating. The external conductor is a rigid stainless steel tube with an internal 20 µm copper coating. There is no bellow on RF side, the bellows giving flexibility to the system is between the outer conductor and the cryomodule flange. No internal water nor air cooling is required for the antenna, cooling of the antenna results from thermal conductivity of alumina and of the RF line. A simple fan ensures external cooling of the coupler.

The coupler can be directly connected to a standard EIA 1”5/8 coaxial line. Three diagnostics are connected to the coupler close to the ceramic window: a cold cathode gauge, a vacuum window with a photomultiplier and an electron pick-up.

Figure 1 shows the coupler during assembly in clean room. Figure 2 shows the antenna part, before assembly. More details about the design of the couplers can be found in [3].

Couplers are manufactured by Canon Electron Tubes & Devices Co., Ltd. Tochigi, Japan.

Figure 1: RF power coupler being assembled in clean room with valve for leak test control.

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Figure 2: RF coupler before assembly. Antenna part.

## CONDITIONING AND TEST

### *Conditioning and Test Bench.*

Four couplers have been manufactured as prototypes for validating the design and the conditioning bench. These couplers were first inspected visually. No defect was seen, neither on the copper parts, nor on the copper coated parts.

Conditioning was performed with a dedicated conditioning box connecting to couplers. The conditioning box acts like a low-pass filter, with a reflection coefficient better than -15 dB from 170 MHz to more than 250 MHz. The frequency of the couplers in operation is 176.000 MHz.

For couplers 1 and 2, the box, the couplers and the vacuum bench were baked at 170 °C during 48 hours. For couplers 3 and 4, the same vacuum bench was used, but box and couplers were not baked.

Figure 3 shows couplers 1 and 2 assembled to their conditioning box.

Figure 3: Two couplers fixed on their conditioning box.

During conditioning and tests, the box was cooled with fans. A Sunon fan (ref. SF23080AT/2082HSL.GN) was also placed at about 10 cm of the ceramic window to cool down this critical part. A temperature sensor was fixed close to the ceramic window, at the opposite of the fan.

No other cooling system was used. The antenna itself was only cooled by thermal conduction to the ceramic, and to the RF line.

For full reflection tests, four coaxial lines were cut, one for 0 dephasing reference, and three lines with lengths corresponding to 30°, 60° and 90° phases compared to the reference. These phases allow to test almost all stationary wave conditions.

### *Desorption Requirements*

The conductance of the system, from the pump to the coupler window was estimated to 11 l/s. The required maximal desorption rate was $5.10^{-6}$ mbar.l/s. This corresponds to a pressure of about $4.5.10^{-7}$ mbar close to the ceramic, at the point of the vacuum probe. Margins must be considered, including the conductance of the pipe to the vacuum probe, and the accuracy of the probe itself. Finally, we chose to validate the conditioning if vacuum was better than $2.10^{-7}$ mbar in the conditioning range.

### *Acquisition and Control System*

The supervision software to control the test bench is implemented with EPICS 3.15 [4], using the IEE framework [5] for deployment.

A single EPICS IOC controls the whole bench, managing acquisition, configuration and automatic conditioning.

This IOC runs on a IOxOS IFC1210 VME card, and performs the high speed acquisitions (RF measurements, PUe and PM) through two IOxOS ADC3111 mezzanine card (8 channel ADC 16-bit 250 Mps). It performs slower acquisitions and controls (analogue or binary) through remote I/O Beckhoff modules using Modbus protocol with EK9000 coupler.

The RF signal entering the test bench is controlled from the EPICS IOC through Modbus using a R&S®SMC100A Signal Generator.

Experiments measurements and controls are archived continuously using EPICS Archiver Appliance [6].

### *Conditioning Automation*

For validating the couplers, we applied a series of conditioning steps, during hours. Conditioning was only done at 100% duty cycle for injection power from 0 to 10 or 18.5 kW (stationary or travelling wave). The power was maintained to a given step as long as the measured vacuum on both couplers was upper than a defined limit. When the vacuum is good enough, a new power step is defined 10% higher. This vacuum limit was first set to $1.10^{-6}$ mbar (first conditioning ramp), then $5.10^{-7}$ (second conditioning ramp), and finally to $2.10^{-7}$ mbar (third conditioning ramp).

A last test was always carried out to verify that the pressure did not exceed $2.10^{-7}$ mbar. Eventually, the third ramp was launched again once or twice if the last test did not pass.

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### *RF Amplifier*

A 20 kW solid-state RF amplifier designed by SNRC [7] and manufactured by ELIBT\ELISRA [8] was used in the couplers test. Figure 4 shows the RF amplifier used for tests and conditioning of the coupler prototypes.

Figure 4: 20 kW amplifier used for conditioning and testing of the couplers.

### *Multipactor Conditioning*

Multipactor was observed for typical injection powers between 500 W and 1 kW in travelling wave as well as in full reflection mode. Before conditioning, the pressure can exceed $5.10^{-5}$ mbar in the multipactor range as measured by the vacuum probes.

In travelling wave, conditioning required about 6 hours to reach a pressure lower than $2.10^{-7}$ mbar for both couplers in the range 500 W – 1 kW. No conditioning was required above 1 kW Conditioning time was not significantly different if the couplers were baked or not.

After conditioning in travelling wave, new conditioning steps were done in stationary wave. For each line length, conditioning required about 3 extra hours to reach a pressure lower than $2.10^{-7}$ mbar for both couplers.

Total conditioning time for each couple of couplers was about three days.

### *High Power Tests*

Tests in travelling wave at 18.5 kW during 6 hours show temperatures reaching 48.4 °C close to the ceramic. The temperature was stable after about 4 hours.

Tests in stationary wave at 10 kW during 3 minutes show temperatures reaching about 50 °C close to the ceramic. The temperature was still increasing.

We proceeded to leak check tests after these high power ramps. No leak was observed. No degradation of the RF performances was seen.

Desorption was observed at this temperature, for baked or not baked couplers. RGA indicates that dihydrogen is mostly desorbed (> 99% of residual gas), followed by water (<1%). Traces of dinitrogen and carbon dioxide are seen (<0.1 %).

## TEST WITH ECTS

Tests in ECTS are described in [2]. The same conditioning was one in ECTS, at room temperature first, and at 4.2 K then. The conditioning test is described in the same ECTS abstract. No difficulty was observed during conditioning and test.

The ECTS allowed to estimate the $Q_{ext}$ factor of the coupler to $8.10^5$. Considering mechanical tolerances on the coupler parts and seals, we expecting a $Q_{ext}$ factor between $0.74.10^6$ and $1.38.10^6$. Thus, the coupling factor is at the limit of the range.

## MANUFACTURING AND TEST OF THE SERIES

These tests validated the SARAF couplers, the conditioning test bench and procedure. The series should be launched in May 2019 for delivery in the end of 2019. The series includes 29 couplers. 14 of these 29 couplers must have been conditioned before second trimester of 2020. This first set of couplers will be assembled on the first two low-beta cryomodules. The remaining couplers will follow.

## CONCLUSION

The SARAF coupler prototypes and their conditioning bench were fully qualified at room temperature and in ECTS. Multipactor was observed but conditioned after a few days in travelling and stationary wave. The manufacturing of a series of 29 couplers will begin very soon.

The conditioning of the series should begin in the end of 2019 for having at least 13 couplers ready for assembly in the second trimester of 2020.

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