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RESULTS OF CEA TESTS OF SARAF CAVITIES PROTOTYPES

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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 identical cryomodules host 6 half-wave resonator (HWR) low beta cavities (β = 0.09) at 176 MHz. The last two identical cryomodules will host 7 HWR high-beta cavities (β = 0.18) at 176 MHz. Low-beta and high beta cavities have been optimized to limit electric and magnetic peak fields in the cavity, and to minimize the dissipated power. This document mainly presents the results with the low-beta cavity prototype in vertical cryostat. This prototype was qualified.

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 low-beta cavities are optimized to $\beta_{opt} = 0.09$ and the high-beta cavity are optimized to $\beta_{opt} = 0.18$. 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.

This document focuses on the results of the low-beta cavity in vertical cryostat. The tests of this cavity with coupler and tuner in a dedicated test stand (ECTS) are presented in [2].

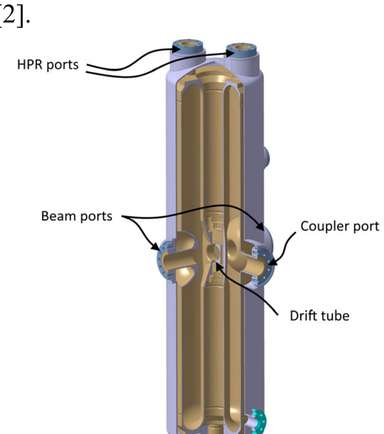

Figure 1: ¾ of the low beta cavity.

RF DESIGN

The frequency target of these cavities is 176.000 MHz in nominal operations. The optimal β, β_{opt}, of the cavities is defined by the β value that *maximizes* the effective shunt impedance at 176.000 MHz. The simulated β_{opt} values are *0.091 and 0.181* $\pm$ 0.001. The accelerating fields is defined at β_{opt}. The low- and high-beta cavities must reach accelerating gradients of *6.5 MV/m and 7.5 MV/m* in operation, respectively. The design accelerating gradients are defined 8% above the operational gradient, respectively at 7.0 MV/m and 8.1 MV/m.

Figure 1 shows a 3D of the low-beta resonator. Figure 2 presents the field maps for the low beta cavities. Figure 2: Electric field (left) and magnetic field (right) in the low-beta cavity.

Table 1 presents the critical parameters for the low- and high-beta cavities. The high-beta cavities are about as long as the low-beta cavity, but the outer diameter is approximately twice as big compared to the low-beta cavity.

More details about the design can be found in [3].

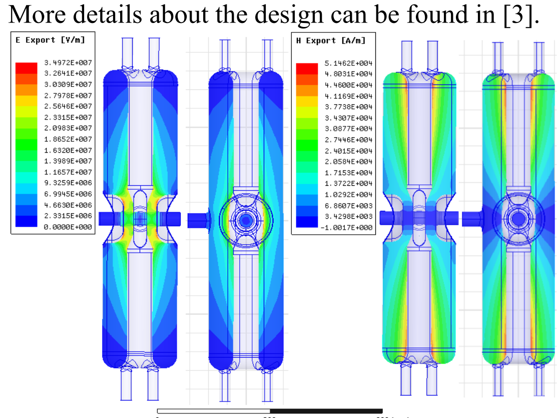

Figure 2: Electric field (left) and magnetic field (right) in the low-beta cavity.

Table 1: Expected Performances of the Low-Beta Cavities

	Low β cav.	High β cav.
β_{opt}	0.091	0.181
Design E_{acc} (MV/m)	7	8.1
Epk_{max} (MV/m)	34.5	35.8
Bpk_{max} (mT)	65.6	65.3
Target Q_0 @ 4.45 K	8.10^8	$1.2.10^9$
R/Q @ β_{opt} (Ω)	189	280
Stored Energy (J)	5.7	16.8
Max. RF power consumption @ 4.45 K (W) & Eacc	7.9	15.5

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CAVITY MANUFACTURING

The low- and high-beta cavities were manufactured by Research Instrument (Bergisch-Gladbach, Germany). Outer, inner conductors and tori were formed in niobium sheets. Beam and coupler ports, as well as HPR ports and drift tubes were machined in bulk niobium.

The helium tank of the low-beta cavity was manufactured with titanium sheets.

Figure 3 shows the low-beta cavity without helium tank waiting for assembly and the high-beta cavity during BCP (Buffer Chemical Polishing). Transport frames are the same for both cavities for comparison.

Figure 3: Picture of the low- and high-beta cavities in clean room waiting for assembly and during BCP respectively.

Q_0 VS E_{ACC} – LOW-BETA CAVITY

All tests of the low-beta cavity prototype presented in the following paragraphs are summed up in Figure 5. Tests were carried out in the CEA vertical test cryostat at 4.2 K.

*First Tests – QFT#1 & QFT#2**

A first series of tests was launched in March 2018. These tests were made after a 150 µm BCP (Buffer Chemical Polishing in Phosphoric-Nitric-Hydrofloric acid mixture, ratio 2.4-1-1) and an HPR. Test #2 was done after warm-up and cool-down of the cavity, without any extra treatment. These tests showed a quench at 4.2 MV/m and 1.2 MV/m.

No field emission was measured, neither with the X ray detector, nor with the electron pick-up.

New Test After New Treatments – QFT#3

Following the first unsuccessful tests, a new test was done, after heat treatment (48 hours @ 650 °C), new BCP (15 µm) and new HPR. A new HPR bench was designed for this test, as we suspected it could be the cause of the previous failure. With a small modification of the bench used for other CEA half wave cavities, it was possible to pass the HPR stick vertically through the small space between the beam ports and the drift tube, allowing to clean up these critical parts more effectively.

No quench was observed for this test, at least up to 11 MV/m. Considering the risk to damage the cavity or the power injection cable, the cavity was not tested above 11 MV/m.

This test was not fully successful, as the Q_0 target at E_{acc} was not reached, around 7.10^8 instead of 8.10^8.

However, as no field emission was measured, neither with the X ray detector, nor with the electron pick-up, the new HPR bench was fully validated. At this stage, as the Q_0 factor was very close to the requirement, we decided to continue the manufacturing process, with the helium tank welding, before working on the improvement of the Q_0 factor.

Test with Helium Tank – QFT#4

The cavity was tested after helium tank welding, without new treatment. The frequency shift during helium tank welding was estimated to about +300 kHz. This frequency shift will have to be reduced for the series production to reach the target frequency. The cavity was under vacuum during welding. Results are almost identical with a Q_0 factor around 7.10^8 after welding.

No field emission was measured, neither with the X ray detector, nor with the electron pick-up.

As the target field was validated, the final steps consisted in improving the Q_0 factor to reach the target. For this purpose we studied the possibility to apply baking.

Test After Baking – QFT#5

Baking of low-beta cavities is known to be an effective way to improve Q_0 factors [4]. Improvements are mainly expected at high-field. This process was successfully tested with the low-beta prototype.

The cavity was baked at 120°C under vacuum during 72 hours, to test the effectiveness of baking on this cavity.

The result is a significant increase of Q_0 at the test field: about a factor 2 at 7 MV/m. After baking the Q_0 factor reached $1.6.10^9$. This result is similar to observations with QWR Spiral 2 cavities [5]. This demonstrates that baking can be a solution if the requirements are not reached.

In these conditions, the cavity was fully qualified in regards to the requirements. The RF power consumption at $1.6.10^9$ is 3.8 W. No field emission was measured, neither with the X ray detector, nor with the electron pick-up.

Test of the Pick-Up Antenna – QFT#6

For SARAF cavities, in order to avoid adding a specific port for the pick-up antenna, we chose to use a loop antenna inserted in one of the HPR ports. Figure 4 shows the tested loop antenna.

[*] QFT : Quality Factor Test.

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This loop antenna was validated by test #6. A decrease of about 20% of the Q_0 factor was observed. It might be attributed to the additional assembly in clean room that could have introduced humidity in the cavity (no additional baking was done after assembly with the loop antenna). The cavity still reached the requirements.

Figure 4: Picture of the loop pick-up antenna.

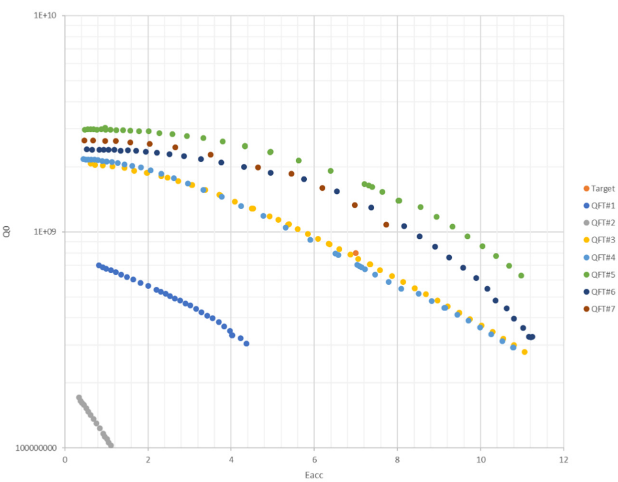

Figure 5: Set of Q_0 tests for the low-beta SARAF prototype in vertical cryostat and ECTS.

Test in the Equipped Cavity Test Stand (ECTS) – QFT#7

A first test of this cavity in the ECTS was done without its power coupler. The Q_0 factor did not change in ECTS. See [2] for more details.

TEST OF THE HIGH-BETA CAVITY

The tests of the high-beta cavity prototype began in March 2019. For now, a quench appears @ 5.4 MV/m without field emission. The reason of this quench is being investigated. New tests are planned in near future.

MANUFACTURING AND TEST OF THE SERIES

The manufacturing of the SARAF low-beta cavity series was launched in February 2019. 14 low-beta cavities will be manufactured and tested.

The process for preparation and test of the series cavities will be the following:

- 1st step: 150 µm BCP on the bare cavity,
- 2nd step after 650°C heat treatment: flash BCP (about 15 µm) and HPR, assembly with the loop antenna and first test before helium tank welding,
- 3rd step after helium tank welding: 120°C baking during 48 hours and final test.

The acceptance test of the first cavity of the series is planned for the last quarter of 2019. One cavity should be qualified every two weeks from the end of 2019 to the middle of 2020.

The manufacturing of the SARAF high-beta cavity series will be launched after validation of the prototype, expected before the end of the third quarter of 2019. 15 high-beta cavities will be manufactured and tested. The test of the first of series is planned after the end of the qualification of the low-beta cavities in the middle of 2020, with the same rate of test.

CONCLUSION

The SARAF low-beta cavity prototype was fully qualified in vertical cryostat and ECTS. The Q_0 factor is almost twice as high as the requirement. Baking was proved to be effective on this cavity to improve significantly the Q_0 factor and to reach the requirement. The manufacturing of a series of 14 low-beta cavities has begun.

Concerning the SARAF high-beta prototype, tests are ongoing. The qualification of this prototype, including tests in ECTS, is expected before the end of the third quarter of 2019.

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