EXPERIMENTAL RESULTS ON 700 MHz MULTICELL SUPERCONDUCTING CAVITY FOR PROTON LINAC.

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Abstract

The first five-cell niobium superconducting cavity (700 MHz, β=0.65) has been successfully tested in the horizontal cryostat CryHoLab. Technological choices like equipment with stainless steel helium vessel and flanges appeared to be viable for the future. Preceding this test, several operations have been performed: field flatness adjustment, chemical etching, heat treatment and RF measurements in a vertical cryostat. Good performances for a multicell cavity were obtained. However, field emission and not yet elucidated phenomenon limit the accelerating field around 16 MV/m.

1. INTRODUCTION

The R&D collaboration on 700 MHz superconducting radio frequency (SCRF) cavities between CEA-Saclay and IPN-Orsay started few years ago in the context of the French ASH (**S**uperconducting **A**ccelerator for **H**ybrid reactor) project, aborted since then.

Nevertheless, the developments of this kind of cavities are still a topical subject because of its involvement in any linear proton accelerator requiring a high energy section. Such projects, using a high intensity beam, are dedicated to produce radioactive ion beams, neutrons for nuclear waste transmutation, or particles for muon colliders and neutrino factories.

Currently, the French SCRF proton cavities research is related to the European projects XADS (e**X**perimental **A**ccelerator **D**riven **S**ystem) and EURISOL (**EUR**opean **I**sotope **S**eparation **O**n-**L**ine). The linac design and the beam dynamics studies defined modules made of five-cell SCRF cavities with several β values (0.47, 0.65, and 0.85). Our first goal was to manufacture and test a 5-cell prototype (β=0.65) in a horizontal cryostat to validate the design and the technological choices. A second step will be to experiment its associated components: the cold tuning system and the power coupler.

2. CAVITY CHARACTERISTICS

The five-cell A5-01 niobium cavity, manufactured by CERCA, was designed on the basis of RF codes simulations [1] and after validation through the results achieved with the A1-05 monocell cavity in a vertical cryostat (Fig.1) [2]. This cavity is characterized by:

- ratios of E_{peak}/E_{acc} and B_{peak}/E_{acc} surface peak to accelerating fields, respectively about 2.32 and 4.48 mT/(MV/m),
- no stiffening rings between cells,
- two lateral ports used for the input coupler and the transmitted power pickup probe,
- an asymmetry in the beam tube diameters (RRR 30 niobium),
- Conflat® CF flanges, bellow and liquid helium vessel, made with 316 L stainless steel, which are copper-brazed on niobium,
- the Nb cells material supplied by Wah Chang (4 mm sheets - RRR>250)

3. FIELD FLATNESS TUNING

To ensure the electric field flatness on the beam axis, it is necessary to pre-tune the multicell cavity, at the room temperature. The tuning procedure consists into a mechanical deformation of each cell by means of steel plates to squeeze or stretch it. The field profile is measured by the perturbation method induced by a small metal bead moving along the beam axis [3].

Three pre-tunings were necessary to improve the field flatness up to E_{min}/E_{max}=92% from the initial values: on receipt of the cavity from CERCA (24%) and after new degradations resulting from the first important chemical etching (75%) and from the heat treatment (65%).

4. CAVITY PREPARATION

4.1 Chemistry

All along RF tests, the cavity has been treated several times by a “Buffered Chemical Polishing”, $HF/HNO_3/H_3PO_4$ acid mixture (1:1:2). To limit the acid volume required for dunk chemistry, the chemical treatment was only made in the inner part of the cavity. The cavity apertures were closed by **P**oly**V**inyl**C**hloride flanges and Viton® O’ring seals protect brazes from the acid attack. A first hard etching of the surface removed a 170 µm thickness. Then several slight chemistries (20 µm) were made to prevent possible surface contamination after each cavity handling (field flatness tuning, heat treatment and helium vessel welding).

Unfortunately, during one chemistry a bad adjustment of the O’ring protection seal caused the acid attack of the

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copper braze at one axial flange. A vacuum leak occurred that was temporarily sealed in using a Stycast® epoxy compound. This cure has been effective until now: even after several thermal cycles, we did not observe any leak on the cavity immersed in He II bath.

4.2 Heat Treatment for Q-Disease

To avoid the important Q-disease effect (curve 2 on Fig.2), due to hydride formation around 100K and observed during a slow cool-down, the cavity has been annealed under vacuum (1.10^{-7} mbar) for one day in the CERN furnace. This treatment is required before the test in horizontal cryostat because in that case a fast cooling down is impossible, the pre-cooling being necessarily carried out by liquid nitrogen at 77K.

During this treatment, we have verified the hydrogen removal from the bulk material with a rare gas analyzer. A 650°C temperature has been chosen, instead of the usual 800°C, to prevent the stainless steel CF flanges brittlement that could appear at low temperature during subsequent RF tests and to preserve the cavity stiffness. The curve 3 on Fig.2 proves the efficiency of the heat treatment at low temperature, an observation already mentioned in an earlier experiment [4].

4.3 Helium Vessel

After heat treatment, the helium vessel [6] was attached to the multicell niobium cavity by TIG welding. An ultimate field flatness check and a new test in a vertical cryostat showed that cavity performances were unchanged by the stainless steel helium tank welding and that the cavity was then ready for horizontal tests in CryHoLab.

5. RF MEASUREMENTS

5.1 Tests in Vertical Cryostat

For the first test, the 5-cell cavity (curve 1 on Fig.2) shows a similar behavior to the A1-05 monocell (Fig.1) with a multipacting barrier around 10 MV/m; but, instead of the limitation by quench at 25 MV/m, we were surprisingly limited at 15 MV/m without any of the usual causes, quench or electrons. We observed and did not find yet an explanation, that when E_{acc} exceeds 15 MV/m the incident power P_i is partially reflected at the cavity entrance, after a time Δt (Fig.3). We suspected a coupling problem and decided, for next vertical test, to change the RF antenna position and put them on the beam axis, instead of lateral ports.

During the second test (curve 3 on Fig.2), after the annealing of the cavity, we noted the electron production by field emission and we observed the same limiting phenomenon at 15 MV/m. This was in spite of the new antenna position. The phenomenon study shows that if we switch off the RF power between each data point, during the "RF-off" time τ, we can extend the Δt time enough to make the RF measurements.

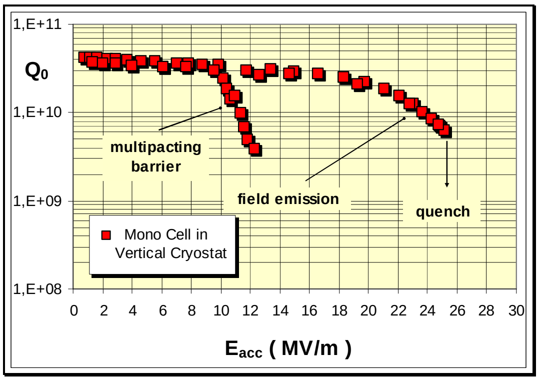

Figure 1: Q_0 vs E_{acc} for the mono-cell cavity (A1-05), in vertical cryostat at 1.7K

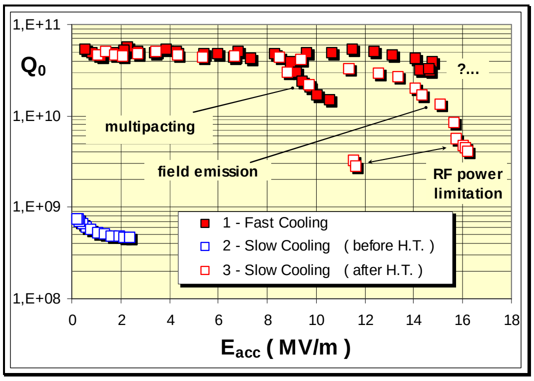

Figure 2: Q_0 vs E_{acc} for the 5-cell cavity (A5-01), in vertical cryostat at 1.7K.

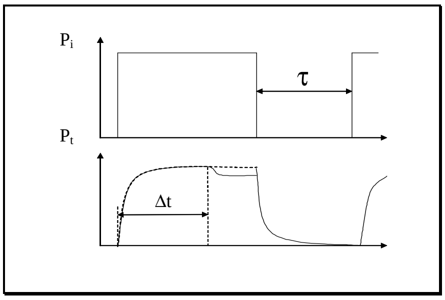

Figure 3: Schematic traces of incident P_i and transmitted P_t powers versus time during the observed phenomenon with $\Delta t = f(1/E_{acc}, \tau)$

By this way, it was possible to exceed the 15 MV/m limit and we then met a more usual "RF power supply limitation" due to the electron emission at 16 MV/m. On the curve 3 (Fig.2) we can see the shift (↔) for the two last data points if we do not switch off the RF power between the measurements. When the E_{acc} value increases, Δt decreases so a longer "RF-off" time is necessary. The τ value, about two minutes, suggests a long relaxation time for the limiting phenomenon. In spite of these difficulties the RF results show good performances for our 5-cell cavity if we compare them with similar multicell cavities [4-5].

5.2 CryHoLab horizontal test facility

For the first time CryHoLab (french acronym of “CRYostat HOrizontal de LABoratoire”) is running with a cryogenic generator [7] (compressor, 120 l/h liquefier-cold box, 2000 l buffer-dewar), instead of liquid helium containers. The pumping system allows the helium bath temperature to decrease down to the working value (1.8 K).

The 5-cell cavity is the first one tested in such conditions. The dynamic cryogenic power consumption of the whole installation at 1.8 K (cryostat, cavity, transfer lines and He bath pumping) is around 20 W (29 l/h). Figure 4 shows the A5-01 cavity, inside CryHoLab, wrapped in super-insulation layers as thermal shielding.

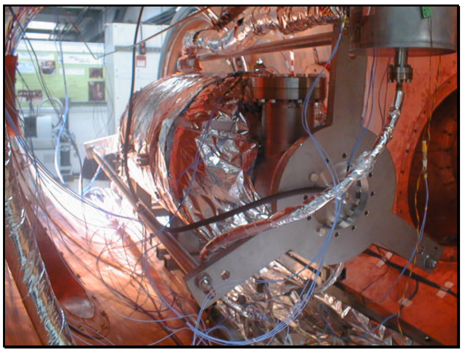

Figure 4: The 5-cell cavity inside CryHoLab.

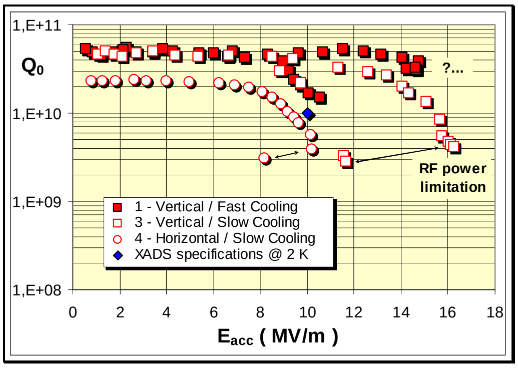

Figure 5: Comparison of the RF tests in vertical and horizontal cryostats

5.3 Tests in Horizontal Cryostat

To be able to make a real comparison between vertical and horizontal tests, and in spite of the electron emission, the cavity is tested without a new cleaning stage. Curve 4 on Fig.5 shows the RF horizontal results with a slight decrease in the Q_0 value at low accelerating field from 4.6 to 2.3 10^{10} due to the change of the residual resistance resulting from the difference of the magnetic field shielding between vertical and horizontal cryostats (from 2 to 20 mG). The same phenomenon in the input power limitation is also observed in CryHoLab but from only 8 MV/m. Using the same “RF-off” method than in the vertical cryostat, it is possible to reach 10 MV/m. But we did not succeed to go through the multipacting barrier, even after we attempted to make a cell by cell RF formation using other fundamental modes than π-mode. It is necessary to carry on the investigations of the limiting phenomenon and to check a possible connection with the lack of stiffeners between the cavity cells.

6. CONCLUSION

The first preliminary results of the multicell cavity allowed to:

- show the good performances of the cavity, above the XADS specifications, in spite of field emission,
- reinforce the technical options and particularly the use of stainless steel helium vessel,
- validate the horizontal RF test facility CryHoLab and the cryogenic fittings.

The five-cell cavity being characterized all along the different stages of its preparation, up to the final RF test in the horizontal cryostat, our priority now is to understand and to solve the experimental event that limits the intrinsic performances of this cavity.

In parallel, we will improve the CryHoLab magnetic shielding and we will clean again the cavity to suppress the electron emission, probably linked to a surface contamination due to pollution in the rinsing water system.

7. REFERENCES

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