PERFORMANCE IMPROVEMENT OF THE MULTICELL CAVITY PROTOTYPE FOR PROTON LINAC PROJECTS

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Abstract

The CEA-Saclay / IPN-Orsay collaboration allowed to manufacture a multicell superconducting RF cavity prototype for proton linac. Since the first experimental results [1], obtained in a vertical cryostat and the horizontal cryostat CryHoLab, the accelerating field E_{acc} has been recently increased up to 19 MV/m with a quality factor $Q_0 = 9.10^9$ and a limitation by quench.

However some improvements are still needed, in particular to suppress the field emission above 16 MV/m.

INTRODUCTION

The French R&D program on superconducting RF cavities dedicated to fit the high energy section (>100 MeV) of high intensity proton linear accelerators (see Fig.1) is mainly supported by two European projects:

- XADS, Preliminary Design Study of an eXperimental Accelerator Driven System. In this concept, neutrons are produced from spallation processes induced by the proton beam interaction with a heavy material target (Pb). These neutrons make up the external neutron source for a subcritical nuclear reactor to sustain transmutation of nuclear wastes,
- EURISOL, Research and Technical Development for the EURopean Isotope Separator On-Line, a radioactive beam facility in Europe. Rare isotopes are produced after the proton beam interaction with the target.

In this context, the CEA-Saclay and IPN-Orsay Laboratories started few years ago a collaboration to design, build and test a multicell cavity prototype for medium beta (β=0.65). At the same time an international collaboration was also established with INFN-Milan for the low beta superconducting cavities (β=0.47) for the Italian TRASCO program [2]. This R&D on multicell superconducting cavities should be continuing within the 6^{th} European framework program with the Integrated Project EUROTRANS (XADS continuation), the EURISOL Design Study and the CARE-HIPPI (High Intensity Pulsed Proton Injector) program linked to the SPL (Superconducting Proton Linac) project at CERN.

CAVITY FEATURES

The five-cell A5-01 cavity (700 MHz, β=0.65), manufactured by CERCA from Wah Chang Niobium sheets (thickness 4 mm - RRR>250), 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). Conflat® flanges, and liquid helium vessel, made from 316 L stainless steel, are copper-brazed on niobium. The mechanical stiffness of the cavity is ensured by the stainless steel frame (20 mm thick) and bracing rods, without stiffening rings between cells. Moreover, the cavity has been annealed under vacuum in furnace (650°C, ~ 1.10^{-7} mbar) to prevent the Q-disease during the RF test in the horizontal cryostat.

EXPERIMENTAL RESULTS

Preliminary Results

The first RF results achieved on this cavity have been discussed in previous papers [1,3]. During these tests, some problems occurred:

- a vacuum leak due to the acid attack of the brazing metal. This leak was temporarily sealed with a Stycast® epoxy compound,

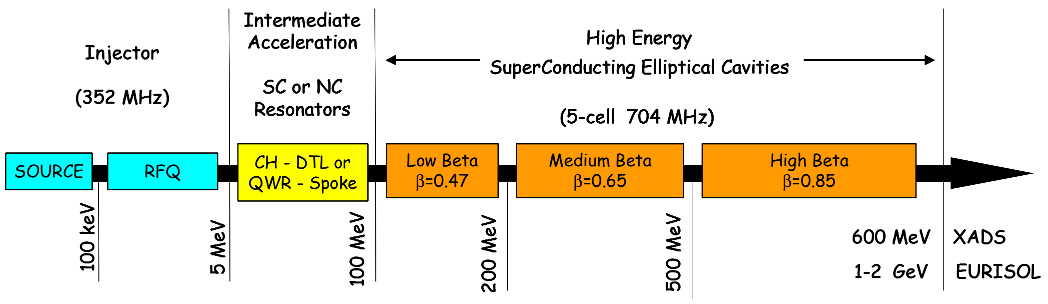

Figure 1: Schematic layout of a high intensity proton linear accelerator.

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• the limitation by strong resistive losses of the accelerating field around 16 MV/m for the test in vertical cryostat and only 10 MV/m in CryHoLab.

New Tests in Vertical and Horizontal Cryostats

To solve the leak problem a new flange has been successfully designed with sealing by indium gasket instead of Helicoflex® rings.

To improve the cavity performances additional chemistries have been applied on its inner surface. Niobium thickness of 35 µm has been removed since the preliminary tests. The chemical treatment procedure is to fill and empty several times the cavity with 55 liters of acid. After a first water rinsing, the cavity is rinsed at high pressure (85 bars) with ultra-pure water (18 MΩ.cm) in clean room of class 100.

After cavity cooldown to the liquid He temperature the surface resistance versus temperature has been measured between 4.2 and 1.7 K (Fig.2). The data fit with the BCS theory by using the Nb parameters (λ_L = 31 nm, ξ_0 = 62 nm, T_C = 9.22 K) allowed to obtain the values of the electron mean free path (190 nm) and the very low residual resistance (2.2 nΩ).

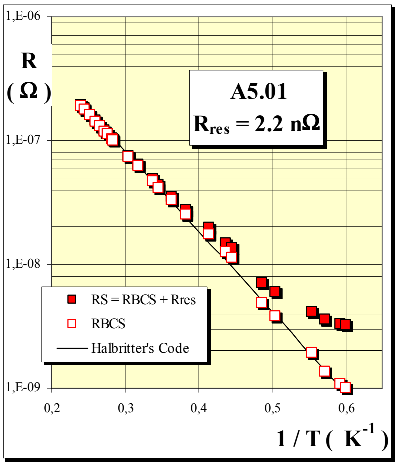

Figure 2: Surface resistance measurement between 4.2 and 1.7 K fitted by the BCS theory.

The quality factor versus accelerating field (E_{acc}) is shown in Fig.3. The accelerating gradient reaches 19 MV/m with a quality factor of 9.10^9 for the RF test in vertical cryostat. Consistent results (18 MV/m - 6.10^9) have been achieved with test in the horizontal cryostat CryHoLab. These values of E_{acc} correspond to electric and magnetic peak fields on cavity surface of about 43 MV/m and 83 mT.

No problems were encountered to easily go through the multipacting barriers. Field emission appeared above 16 MV/m. The cavity performances were limited by thermal quench located in the cell n°1 or n°5. This localisation of the quench became possible by means of the TM_{010} - $4\pi/5$ mode, because in this case, the energy is mainly stored in the end cells of the cavity.

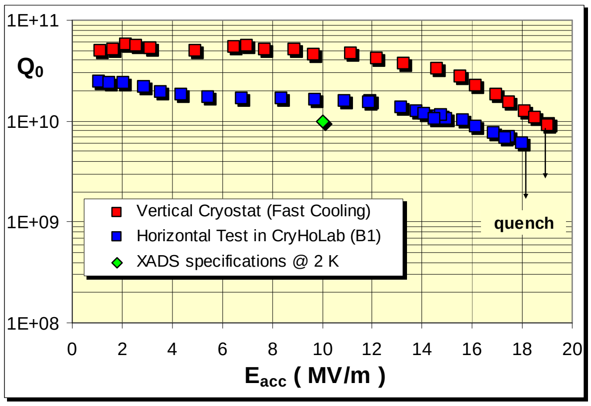

Figure 3: Q_0 vs. E_{acc} in vertical and horizontal cryostats.

Comments

• The improvement of the cavity performances by comparison with the previous results [1] is probably due to a better surface quality achieved after additional chemistries. In particular the non understood phenomenon (local defect) that limited the accelerating field last year did not appear this time.

• We can see in Fig.3 a difference of the quality factor value between the vertical and horizontal RF tests, for low and middle accelerating fields. The cause is probably a less efficient magnetic shielding of the horizontal cryostat CryHoLab: change of intensity in the magnetic coils (dynamic shielding) modifies the Q_0 values (white and blue squares in Fig.4).

• On other hand no change is observed in vertical test when the cavity is cooled down quickly (red data in fig. 4) or slowly with a stage of several hours around 100 K (white and red squares). Therefore, since the cavity heat treatment at 650°C the hydrogen did not pollute the niobium during the seven successive chemistries (total thickness removed 85 µm).

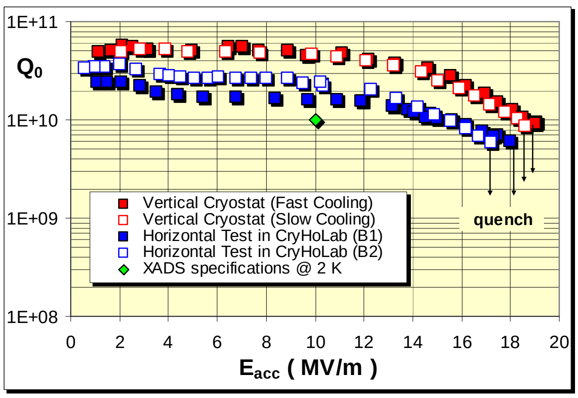

Figure 4: Q_0 vs. E_{acc} for A5-01 at 1.7 K showing the influence of magnetic shielding and slow cooling down.

LORENTZ FORCE DETUNING

A deformation of the cavity shape appears at high accelerating fields because of the radiation pressure. The result is a resonance frequency shift, characterized by the Lorentz force coefficient K_L:

$$\Delta f = K_L \; E_{acc}^2$$

This coefficient has been calculated [4] with the finite element code CAST3M in different boundary conditions for the cavity stiffness (see Table 1).

	Fixed End	**Helium Vessel & Tuner**	**Free**
K_L Hz / $(MV/m)^2$	- 2.27	- 4	- 30

Table 1: K_L theoretical values computed with CAST3M code.

During the RF tests we have measured the frequency variation of the cavity Δf versus E_{acc}, but the experimental boundary condition was different from the three conditions above. The cavity was equipped with its helium vessel but without tuner and the stiffness element was the “stainless steel frame – bracing rods” system shown in Fig.5.

Figure 5: Stainless steel frame and bracing rods as cavity stiffness.

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The experimental determination of K_L during several tests in vertical cryostat was around -7 Hz / $(MV/m)^2$, this value is in the range of the computed values and shows the relative efficiency of the stiffness system.

But in the horizontal cryostat this value was strongly deteriorated (-13 Hz / $(MV/m)^2$ in Fig.6). The reason seems to be due to the combination of the lack of stiffening rings between cavity cells and the heat treatment at 650°C causing a diminution of the mechanical stiffness of the whole system. In horizontal position the bare cavity showed indeed sag of few millimetres in the middle of the cavity length. Simulations are started to see if it is the only cause of this K_L degradation.

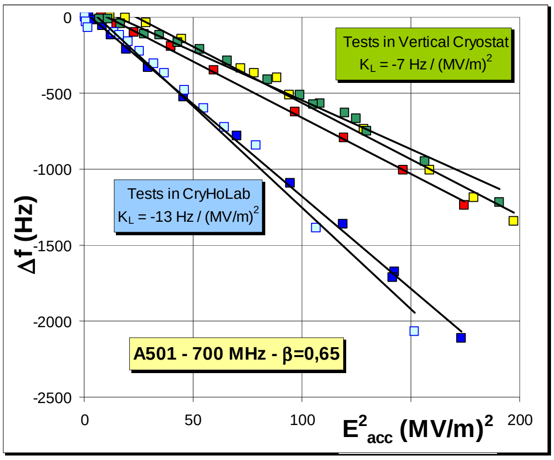

Figure 6: K_L experimental measurements in vertical cryostat and CryHoLab.

CONCLUSION

By comparison with the preliminary RF tests [1] carried out on the 5-cell cavity A5-01, we have found with these new series of tests a more usual behaviour of the cavity with an accelerating field limited by thermal quench around 19 MV/m.

Nevertheless some technical modifications should be undertaken in the future:

- the nozzle design of the high pressure rinsing to suppress the electron field emission which appears systematically for this cavity shape, whereas we do not observe such electron emission on TTF cavities.
- the magnetic screening of CryHoLab to decrease the residual resistance and increase Q_0 at low accelerating fields. A passive shielding with mu-metal sheets around the helium vessel could be considered.
- the cavity stiffness, especially if we want to use this cavity design for pulsed proton accelerator projects.

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