FIRST COLD TESTS OF THE BETA=0.12 LADDER RESONATOR AT LNL

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Abstract

The Ladder resonator is a 4-gap full Nb cavity suitable for the 0.1< β <0.2 range of high current proton linacs. A beta=0.12 Nb prototype of this cavity has been built by E. Zanon SpA (Schio, Italy) on the basis of LNL design. In this paper the construction procedure of such cavity, as well as the tuning steps necessary to match field and frequency requirements are recalled. Finally, the main outcomes of the first cryogenic test performed at LNL in July 2007 are described.

THE LADDER RESONATOR

The 4-gap Ladder resonator has been proposed [1] for the very low beta section (β =0.1÷0.2) of high current proton linacs in a variety of applications: production of exotic ion beams, transmutation of nuclear wastes, spallation neutron sources, neutrino factories, and technological neutron irradiation tools. Such a cavity is capable of providing efficient acceleration in this velocity range, thus allowing to significantly diminish the number of accelerating cavities and the overall linac length. The accelerating field is fully flat along the four gaps, leaving negligible extra space in the longitudinal direction. Indeed, the possibility to equip the resonator with two large flanges allows easy internal inspections, surface treatments, and possible repairs.

In the following table the main parameters of the ladder resonator are outlined

Table 1: Ladder Resonator Main Parameters

Parameter	Nominal Value
Frequency	352.2 MHz
Energy Gain @ β=0.12	1.15 MeV
$E_{s,p}$	20 MV/m
Rf coupling	1.2%
Internal length	196 mm
Gap length g_0	25 mm
Beam Bore Diameter	25 mm
Stem Height h	450 mm
Stem thickness	26 mm
Q_0 @ 4K (assumed)	$5\cdot10^8$
Synch. Phase ϕ_s	-27^o
Γ=U/Eacc^2	$5.64\cdot10^{-14}$ J(V/m)^2

In the following figures the behavior of the electric field in the mid-plane of the cavity and of the magnetic field on the central stem are shown (HFSS simulations).

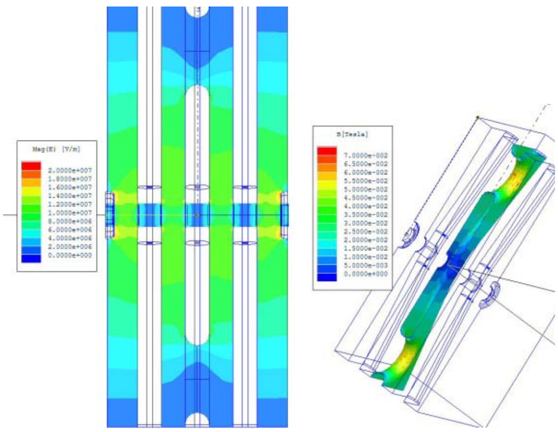

Figure1: Electric (left) and magnetic (right) fields given by HFSS simulations

The TTF curve of the cavity, calculated as

$$TTF = \frac{\int_{-L/2}^{L/2} E_z(0,z)\cos(\frac{2\pi z}{\beta\lambda})dz}{\int_{-L/2}^{L/2} |E_z(0,z)|dz} - \tan(\phi_s)\frac{\int_{-L/2}^{L/2} E_z(0,z)\sin(\frac{2\pi z}{\beta\lambda})dz}{\int_{-L/2}^{L/2} |E_z(0,z)|dz}$$

shows a maximum equal to 0.92 in correspondence of the design beta value. Neverthless, as the gap widths were varied during the construction procedure with respect to the design value[2], also the sensitivity of the ladder cavity to non uniformities in gap widths and/or E field amplitudes along the four gaps was also studied. In fact, let g_i (i=1,..,4) be the gap widths, V(z) the on-axis longitudinal component of the electric field and V_i the corresponding peak E values. The investigation about the variation of TTF due to the cases mentioned below was considered (Figures 2 and 3)

a) Non-uniform field in the four gaps but equal gap lengths
b) Uniform field in the four gaps and inequal gap lengths
c) Nominal case

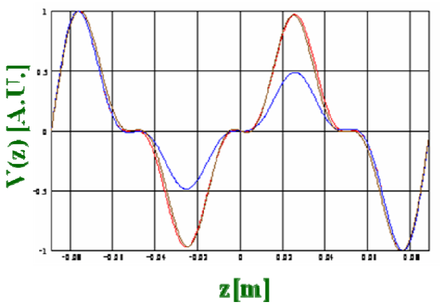

Figure2: Behaviour of the E_z axial field for Non-uniform field in the four gaps ($V_2=V_3=0.5\cdot V_1=0.5\cdot V_4$) and $g_1=g_2=g_3=g_4=g_0$ (blue curve), uniform field in the four gaps and $g_1=g_4=g_0+1$mm, $g_2=g_3=g_0-1$mm (brown curve) and the nominal case (red curve)

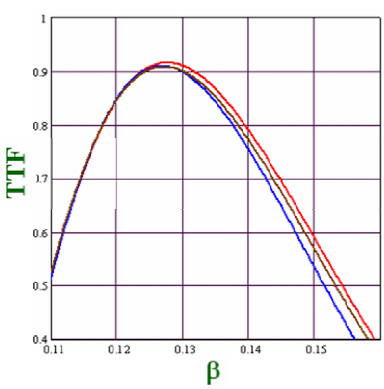

Figure 3: corresponding TTF values due to E_z on-axis fields of Figure 2.

From the above figures it can be seen that, if we compare the cases a) and b), the latter effect is less important than the former and causes only a slight effect on the β acceptance. In conclusion, it is largely preferable to obtain good field flatness at the expense of gap length uniformity (as far as variations smaller than about ±2mm of the gap lengths are considered) than vice versa.

COMPLETION OF THE CONSTRUCTION PROCEDURE: BCP AT CERN

In July 2006, after the completion of the construction procedure, the cavity was sent to CERN in order to undergo BCP. This was carried out in a few steps, in order to check the frequency variation as the niobium was removed from the cavity. As a point of reference, first estimation of the effect of BCP was performed assuming that a 0.1 mm layer is uniformly removed from the internal surface of the cavity. The associated volume variation produces a frequency shift of about Δf_{ce}= -100 kHz. At the end of the procedure (carried out in four steps) the overall Nb thickness removed was equal to about 150 µm, causing a frequency variation from 351.863 MHz to 351.747 MHz , a value very close to the target frequency of f^*-Δf=352.200 MHz-0.550 MHz=351.650 MHz, and in any case within the ±150 kHz tuning range [2]. In such expression Δf takes into account the cavity shrinkage due to both temperature and pressure variations with respect to 300 K and 1atm, once the cavity is put in operation.

FIRST RF TESTS AT 4K

In July 2007 the RF cryogenic tests were performed. The cavity assembly foresaw the usage of two side plates made in Nb sputtered on Cu, as in the case of PIAVE SRFQ's. During the fabrication prodedure of the plates a surface contamination occured. It was due to the silvered screws used for the fixing of the plate during the sputtering process. Neverthless it was decided to proceed with the power test anyway. In fact such test was meant as a verification of the following issues:

- Mechanical compatibility with the cryostat
- Vacuum tightness
- Cooling setup
- RF Coupling
- Measurement System

The cryogenic tests were performed by tailoring a cryostat already used for the ALPI QWR resonators' test. Such arrangement, although suited for our tests, did not permit a rapid cooling of the cavity (Figure 4).

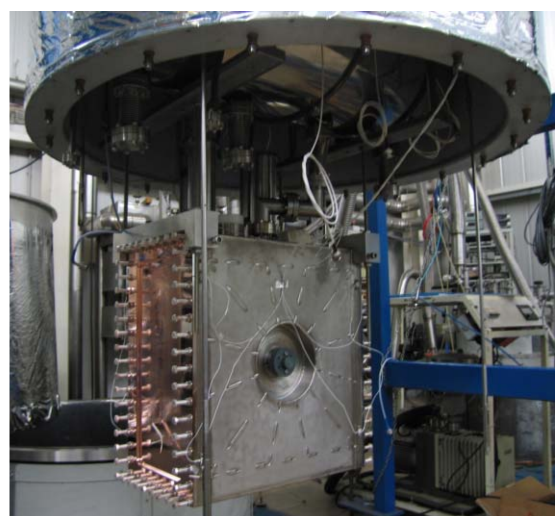

Figure 4: The ladder resonator, equipped with Cu, Nb-sputtered plates, support, and RF lines, being inserted into the test cryostat (July 2007).

In the following the test operation and the RF measurement sequence will be described

Test operation:

1. Cavity baking up to about 340 K, kept at 330-340 for 20 hrs, with subsequent screen cooling with heaters on. The vacuum level in such condition is equal to 1.7×10^{-7} mbar
2. Cavity conditioning at room temperature (270 K) in CW (25 W) and then in pulsed regime (2.5 kW peak power). In this situation the maximum attaianble coupling coefficient was equal to 0.22.

No multipacting level was detected under 0.5 MV/m.

3. Cavity cooling by radiation for 5 days down to180K; to 77 K by liquid nitrogen in 4 hours; then to 4.2 K in 3.5 hours.

The data acquisition and the measurement setup is an improved version of the mobile measuring system for characterization of superconducting cavities that has been put into operation at LNL [3] and a RF power amplifier of 2.5 kW was employed. The coupler was an inductive adjustable loop designed on purpose. In the following the main outcomes of the RF measurements are outlined

At cryogenic temperature the frequency of the cavity is equal to 352.237 MHz. This confirms the effectiveness of the tuning procedure (the error on the frequency is 0.01% only).

The Q-curve, measured in critical coupling condition as soon as the cavity reached 4.2 K is presented in fig. 5 (red triangles). Q_0 is $2.3x10^8$ but a Q switch decreased the Q value to around $1x10^8$. The accelerating field could not exceed 1.2 MV/m.

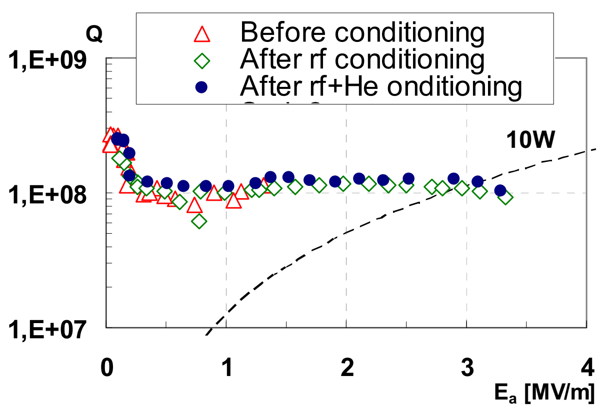

Figure 5: Q_0 vs. accelerating field measured duruing cavity tests.

The day after the cavity was conditioned in pulsed mode for three hours. The maximum power was limited by the power handling capability of the rf lines.

In the following Q measure (green squares) the cavity reached 3.3 MV/m, limited by thermal instability. This is probably connected to the poor quality of the end-plates sputtered film.

A further three hours of rf conditioning in presence of He gas at a pressure of $3x10^{-5}$ mbar practically did not improve the performance (blue circles). Before this last measurement the cavity was warmed up over the critical temperature to release the trapped magnetic field.

Although no leak was detected in the test cryostat and the multipacting conditioning proceeded without any particular problems, the non optimal RF joint between the cavity and the plates, as well the surface contamination of the latter, prevented reaching the full field specifications.

PERSPECTIVES AND FUTURE WORKS

The cavity performances are supposed be improved during the next measurement campaign, upon taking the following actions

- Re-sputtering of the Cu end plates
- Improvement of the joint strength between the plates and the cavity
- Improvement of the RF lines power-handling capabilities
- Improvement of the cleaning and mounting setup

REFERENCES

[1] V. Andreev et al., Physical Review Special Topics: Accelerators and Beams Vol. **6**, 040101 (2003).

[2] A. Palmieri, E. Bissiato and G. Bisoffi , EPAC 2006 Edimburgh (UK), June 2006, p.451

[3] S. Stark et al. EPAC 2006 Lucerne (Switzerland), June 2004, p.692.