RF TESTING OF THE TRASCO SUPERCONDUCTING REENTRANT CAVITY FOR HIGH INTENSITY PROTON BEAMS

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Abstract

A superconducting reentrant cavity for low beta, high intensity proton beams has been designed, built and tested at LNL after chemical polishing at CERN. This single gap resonator is a prototype for the low beta section of the TRASCO 30 mA proton linac, designed aiming at full beam transmission even in case of failure of one resonator. Rf performance, multipacting and mechanical response of the cavity in the first low power tests will be reported.

1 INTRODUCTION

The driver accelerator for the TRASCO project [1] is a 1.6 GeV, high current (30 mA cw) proton linac which includes a superconducting 5-100 MeV section [2]. The beam is needed to feed a sub-critical reactor for nuclear waste transmutation. A special requirement of this linac is a very high reliability, necessary to prevent beam interruption longer than 1 second which could damage the reactor. A way to meet this requirement in the medium energy section (5-100 MeV) is splitting the RF power in a large number of short cavities, as described in ref. [3] and [4].

We have designed a 352 MHz, superconducting reentrant cavity able to fulfil the TRASCO requirements in the all 5-100 MeV section [5]. Important characteristics are: a 30 mm bore diameter, to reduce the risk of beam losses; axial symmetry of the accelerating field to prevent emittance increase; single, 30 mm long gap, for very wide velocity acceptance; 135 mm cavity length along the beam axis (without tuner); simple geometry, aiming at a low cost production cycle. The double wall design, where the inner and outer shells are connected together by means of hollow rings, allows keeping a relatively light structure in spite of the large force applied by the helium pressure to the flat niobium walls (fig. 1).

A major issue was the optimisation of the shape to prevent high field multipacting. The reentrant geometry could suggest the existence of significant multipacting, as in pillbox cavities; our simulations, however, showed no high field multipacting after the cavity geometry was properly optimised.

Table 1. Reentrant cavity parameters

Total length	135	mm
effective length	80	mm
bore radius	15	mm
gap length	30	mm
frequency	352	MHz
U/E_a^2	0.034	$J/(MV/m)^2$
E_p/E_a	3.05	
H_p/E_a	30.6	Gauss/(MV/m)
$\Gamma=R_s\times Q$	83.9	Ω
β	≥ 0.1	

2 CAVITY CONSTRUCTION

During 2001 we have built a prototype of this cavity. The inner resonator shell and the reinforcing rings are made of 3 mm thick, RRR≥250 niobium; the outer shell is made of normal grade material.

Figure 1. The reentrant cavity in various stages of construction.

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The shells shapes have been obtained by cold forming; the same manufacturer performed the mechanical construction and electron beam welding.

The resonator underwent chemical treatment at CERN. Three treatments for a total time of 50’ with a 2:1:1 solution were applied, followed by deionised water rinse and ethanol rinse.

Figure 2. The reentrant cavity assembled in the test cryostat.

3 MEASUREMENTS AND RESULTS

This first set of measurements had the aim of determining the rf and mechanical properties of the resonator, and the comparison with the calculated parameters and the design requirements. The test was performed without any tuning device. To reach critical coupling in the absence of beam loading, we mounted on one beam port opening a low power, movable capacitive coupler derived from our standard inductive couplers for low beta cavities (fig. 2). The cavity was mounted in our test cryostat in a normal (no clean room) environment. For the rf test we had at our disposal a new, home-made 2.5 kW solid state amplifier [6].

We did three measurements. The first one was done after chemical polishing; the rf coupling was very weak and prevented us to do a sufficient conditioning. The test was interrupted after a vacuum breakdown at 4.2K caused by the rupture of one rf feedthrough.

The second test was done after re-adjustment of the coupler position and repair of the rf feedthrough, with no cleaning of the cavity. The third test was done after high pressure water rinse (HPR), performed by spraying, with a commercial nozzle, 100 bar water from outside the cavity through the rf and the beam port openings.

In addition to the Q vs. E_a curves, we measured also the frequency change induced by helium pressure fluctuations and the Lorenz force detuning. No tuning device was mounted on the resonator.

Multipacting behaviour

During the test we found a low field MP level at about 0.029 MV/m (~2.3 kV on the gap), and some very weak ones below that. During the first test, MP could not be properly conditioned because of the insufficient coupling, and the main level appeared at 4.2 K, disturbing our pulsed operation. In the second and third tests, MP was completely removed by conditioning at room temperature with a few tens of watts rf power. No multipacting was found at high field, confirming the TW-TRAJ code predictions [5].

Helium pressure and Lorenz force detuning

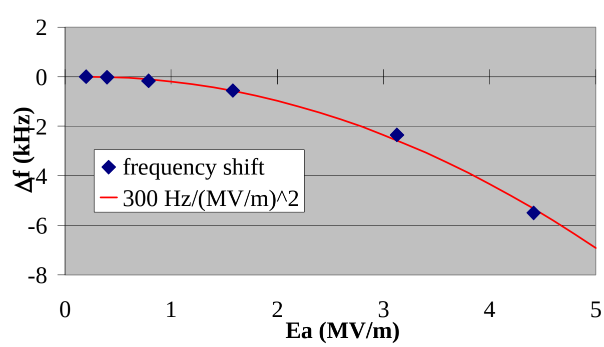
The measured resonator frequency was 348.673 MHz; a final frequency adjustment by plastic deformation to reach the 352 MHz is foreseen after the 4.2 K test. The frequency response to pressure was tested varying it from 0 to 1 bar in the helium vessel. The resulting value is df/dP= 258 Hz/mbar; the value calculated with the I-DEAS and HFSS codes was 45% lower, i.e. 140 Hz/mbar.

The Lorenz force detuning was measured in the range from 0.2 to 4.4 MV/m (see fig. 3); the frequency shift is about -300 Hz/(MV/m)^2, while the calculated value was -170 Hz/(MV/m)^2, again 43% lower.

The lower measured mechanical mode frequency was about 195 Hz, very close to the value of 203 Hz obtained by the simulation code.

The calculated mechanical behaviour and its effect on the frequency seem in an acceptable agreement with the experimental results.

Fig. 3. Lorenz force detuning measured data.



Rf performance

The resonator performance at 4.2 K in the three different measurements is shown in figure 4.

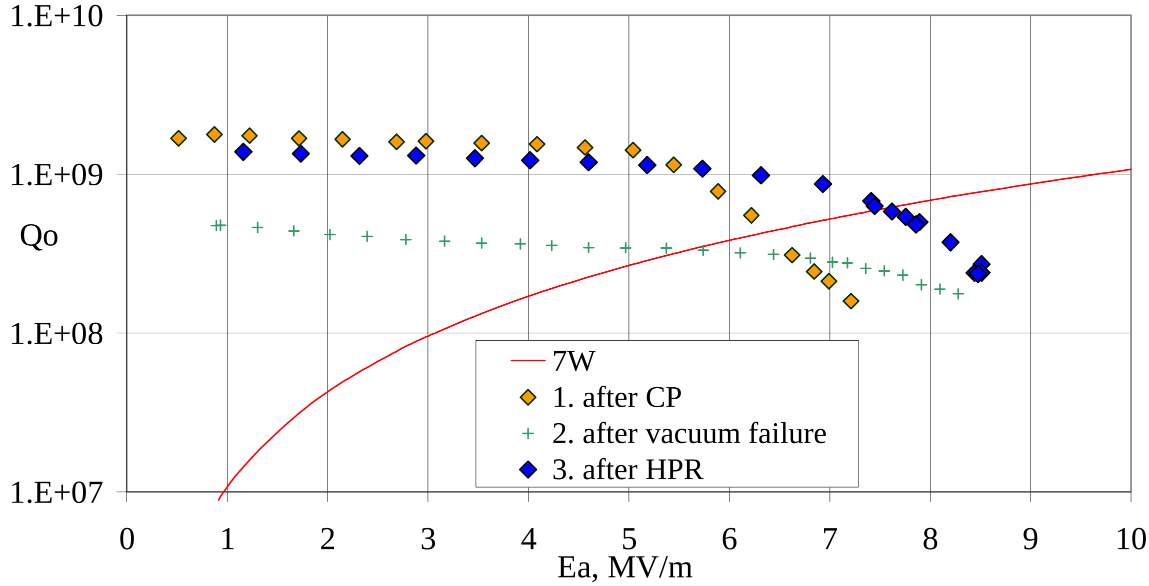


Figure 4. Q vs. E_a curves of the three measurements.

The best quality factor was measured in the first test after chemical polishing. The value of $Q_0=1.7\times10^9$ corresponds to about 49 nΩ total surface resistance (about 10 nΩ residual), showing a rather good surface quality. The first curve shows field emission starting from 5 MV/m. The nominal 7W gradient was 6.3 MV/m. The design value for the TRASCO linac is 8.3 MV/m at 7W.

The second curve, measured after a vacuum breakdown and cavity exposure to air, shows a much lower Q caused from dust contamination; the possibility of doing some pulsed power conditioning, however, could bring the maximum gradient up to 8.3 MV/m.

The last curve, measured after HPR, shows a partial recovery of the surface quality (R_S~72 nΩ total); after about 30' helium conditioning with 600 W pulsed rf power (the maximum allowed by our coupler), the cavity could reach 8.5 MV/m at 25 W, and 7.5 MV/m at the nominal 7 W power.

4 CONCLUSIONS

We have built and tested a 352 MHz superconducting reentrant cavity for the TRASCO linac. The measured rf properties are consistent with the expected ones, and the mechanical properties are in a reasonable agreement with the calculated values.

The 7 W measured gradient of 7.5 MV/m, although slightly below our design specifications, seems already satisfactory for the planned applications, and further improvements can be expected after HPR with an internal nozzle and installation of a high power coupler.

The measurements have demonstrated that low-β reentrant cavities can be operated at high gradient and can be made free from dangerous multipacting.

5 ACKNOWLEDGEMENTS

We wish to dedicate this work to the memory of Jerzy Sokolowski, pioneer of superconducting reentrant cavities, who was to many of us precious collaborator and excellent friend.

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