RF TESTS OF THE SINGLE CELL PROTOTYPES FOR THE TRASCO β=0.47 CAVITIES

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Abstract

Several single cell prototypes of the β=0.47 cavities for the TRASCO Program have been built and tested. The cavities have been fabricated both with reactor-grade Niobium sheets (RRR > 30), mainly to test the fabrication procedure, and with high RRR sheets (> 250). All tests, even for the low-grade niobium cavities, have outperformed the design specifications of E_{acc} = 8.5 MV/m with a $Q_0 > 10^{10}$. The better of the two high RRR Nb cavities reached accelerating gradients corresponding to peak surface electric fields up to 74 MV/m and a surface magnetic field up to 138 mT. A thorough discussion of the RF tests and of the perspectives and limits of the use of low grade Niobium is presented.

1 INTRODUCTION

The TRASCO program in Italy [1] is dedicated to the design and prototypical activities for a superconducting linear accelerator intended to provide an intense proton beam (30 mA CW, at 1 GeV) that, by the spallation process on a lead bismuth target, will deliver the high neutron flux needed to sustain the fission process in a subcritical nuclear reactor for the transmutation of nuclear wastes (following the concept of Accelerator Driven Systems, discussed in [2]).

For the high energy end of the linac (above approximately 100 MeV), the technology of elliptical bulk niobium cavities (at the frequency of 704.4 MHz) has been selected as the most promising available candidate for an efficient and reliable linac design.

In the framework of an international collaboration with a similar national program in France, we selected the geometries of the reduced β cavities for the proposed linac design (namely at the geometrical values of 0.47, 0.65 and 0.85) by an optimization process that took in account both the electromagnetic and the mechanical design [3,4].

Up to now, four single cell cavities of the β=0.47 geometry has been manufactured by one of the industrial partners of the TRASCO program, the Italian company Zanon [5]. The first two cavities, intended mainly for the testing of the dies and of the fabrication tooling and the assessment of the e.m. performances, has been built using low-grade (certified RRR>30) niobium sheets. After the fabrication and dimensional checks, two cavities have been built using high quality (RRR>250) niobium sheets.

All four cavities have been chemically treated and tested at cryogenic temperatures and the results of the RF tests are presented in the following paragraphs.

The fabrication of two complete five-cell cavities equipped with the main coupler and high order modes (HOM) ports has been recently launched.

2 FABRICATION OF THE SINGLE CELL PROTOTYPES

The cavities were fabricated by Zanon, using the procedure described in the following. A niobium sheet of 4 mm thickness has been used to form the cavity half-cells. The equator and iris regions were deep drawn using two sets of dies. Dimensional checks with a reference shape and a 3D measuring machine were performed after the deep drawing process. The half-cell was mounted on a support in order to trim the equatorial and iris surfaces for the electron beam weld. Each cut-off tubes was rolled from a 3 mm niobium sheet and electron beam welded, a stainless steel (316LN) Conflat flange was then vacuum brazed at one edge and the tube EB welded to the half cells (from both sides). Finally, the two half-cavities were assembled on a special tool for the tack welding preceding the EB equatorial weld from outside.

The main cavity parameters are summarized in Table 1.

Table 1. β=0.47 single cell cavity parameters

Geometrical β	0.47
Nominal Frequency [MHz]	699.5
E_p/E_{acc}	2.90
B_p/E_{acc} [mT/(MV/m)]	5.38
Geometrical factor [Ohm] ($G=R_sQ$)	147.8
R/Q [Ohm]	37.07
Iris bore radius [mm]	40.0
Cell length (iris to iris) [mm]	100.0
Wall inclination [deg]	5.5
Equator ellipse aspect ratio	1.6
Iris ellipse aspect ratio	1.3
Cavity Diameter [mm]	187.04
Length of each beam tube [mm]	160.0

3 RF TESTS

The low-grade niobium TRASCO single cell cavities (Z101 and Z102) were manufactured in Spring 2000 and sent to CEA/Saclay for chemical treatment and RF tests, performed in July 2000 (Z101) and June 2001 (Z102). After the final minor corrections to the dies and the procurement of the high grade niobium sheets, the Z103 and Z104 cavities were fabricated and sent to CEA/Saclay (Z103) and to TJNAF (Z104) for chemical treatments and RF tests in October and November 2001.

3.1 Operating Surface Field Limits

The requirement for the cavity operation in the linac design is to provide an accelerating field of 8.5 MV/m at an unloaded Q_0 value of 10^{10} in a five-cell structure. The ratio of peak surface electric fields to the accelerating field is higher in a five-cell cavity with respect to a single cell cavity built with the internal shape. The reason for this is due to the fact that the field is concentrated at the iris regions and the leaking from the cut-off tubes allows lower surface electric field values at the end cells. A smaller difference is seen in the peak surface magnetic field, which is concentrated at the equator region and is much less influenced by the presence of the cut-off tubes.

Table 2 summarizes this effect, listing the field ratios and the peak surface fields in the single cell and five-cell cavities, at the same value for the accelerating field: 8.5 MV/m (that was set in the design to keep the peak magnetic field at 50 mT).

Table 2: Field ratios and peak surface fields at the design accelerating field in the single cell and five-cell cavities

	Single cell	**Five-cell**
E_{acc} [MV/m]	8.5	
E_p/E_{acc}	2.90	3.57
B_p/E_{acc} [mT/(MV/m)]	5.38	5.88
E_p [MV/m]	25	30
B_p [mT]	46	50

Due to the nearly 30% increase in the peak surface electric field of the five-cell cavity with respect to the single cell, and to provide an insight of the significance of the RF tests with respect to the expected multi-cell performances, in the following paragraphs the cavity tests will be presented in terms of peak surface fields (and not only in the usual terms of accelerating fields).

3.2 Low Grade Niobium Cavities Tests

In spite of the rather poor (RRR>30) specifications of the reactor grade niobium sheets used for the fabrication of these cavity prototypes, the performances reached in the RF tests exceeded the TRASCO specifications.

The cavities were chemically treated and tested at CEA/Saclay, without any heat treatment. A buffered chemical polishing (BCP) treatment with an acid mixture of HF, HNO_3 and H_3PO_4 (in the ratio 1:1:2) for nearly two hours was used to remove approximately 100 µm from both the internal and external cavity surfaces. The cavities were then fit in a high pressure rinsing (HPR) system and dried for a few hours in the clean room.

The results of the 2 K tests are presented in Figure 1, where the Q_0 is plotted as a function of the peak (electric and magnetic) surface fields and of the corresponding accelerating field of the five-cell structure. Since these cavities were limited by a thermal quench induced by the magnetic field, we have used the peak magnetic field and the geometrical ratio B_p/E_{acc} of the five-cell structure in order to provide the estimate of the multi cell cavity performances in terms of accelerating field. In terms of single cell cavity performances, these cavities were operated up to 10.9 MV/m of accelerating field. The star in the picture shows the design values for the TRASCO linac specifications. Above the last experimental point (32 MV/m peak electric field and 58 mT peak magnetic field) the cavity quenched abruptly, due to the low thermal conductivity of the low RRR material and the presence of small (resistive) defects.

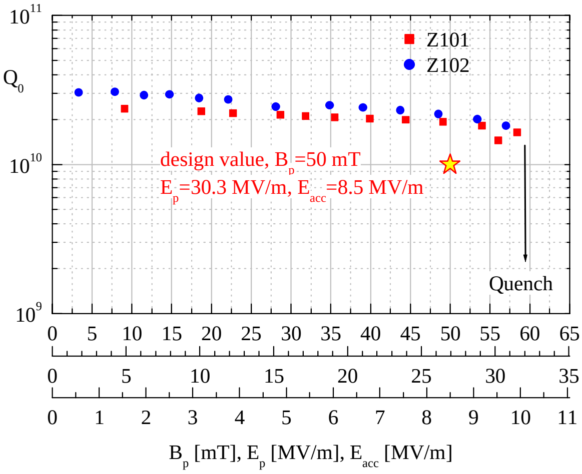

Figure 1: RF tests of the Z101 and Z102 cavities.

3.3 High Grade Niobium Cavities Tests

The Z103 and Z104 cavities were fabricated using high RRR material, after the successful tests described in the previous paragraph. The cavities were sent to CEA/Saclay and TJNAF, where they followed the same procedure described in the previous paragraph before the RF tests.

Both cavities reached outstanding performances, outreaching with a wide margin the TRASCO design goal (summarized in Table 1). The results of both cavities tests at 2 K are presented in Figure 2, again in the same format as the previous Figure. The cavities reached an equivalent five-cell accelerating gradient of 16 and 19 MV/m respectively (18 to 22 MV/m in term of single-cell E_{acc}) at a Q_0 of 10^{10}. Z103 tests were limited by RF power and the Z104 cavity quenched at 138 mT of magnetic field.

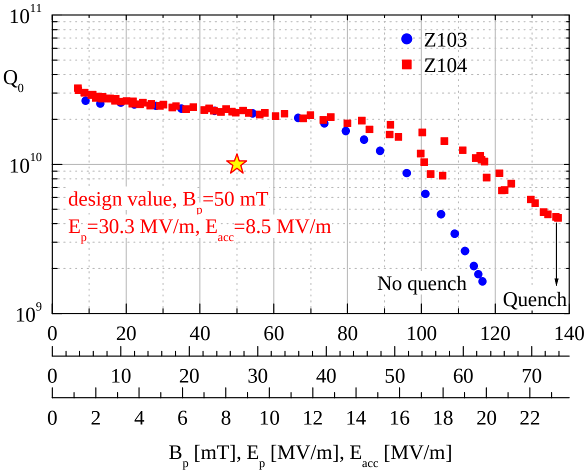

Figure 2: RF tests of the Z103 and Z104 cavities.

Above ~38 MV/m of peak surface field the X-ray detectors were indicating the presence of field emission. The equivalent five-cell accelerating field has been evaluated as in Figure 1. We have however to note that the performance of Z103 was limited by field emission, and due to this fact, would be limited to lower accelerating fields (nearly 27% lower, as determined by the different peak electric field ratio of Table 2).

3.4 Surface Resistance and Niobium RRR

From the measurements of the Q_0 at low power and the knowledge of the cavity geometrical factor the surface resistance at 2 K was estimated to be 4 nΩ (±0.5 nΩ). Due to the contribution of the BCS term to the surface resistance [6], we estimated the residual resistance to be in the range 1-2 nΩ. Figure 3 shows the low temperature behavior of R_s, derived from the low power tests.

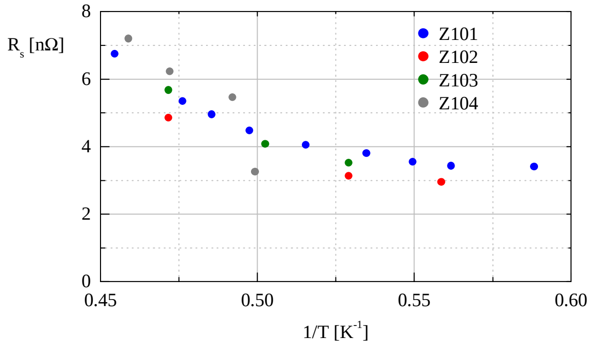

Figure 3: Low temperature behavior of R_s determined from the low power Q_0 measurements.

Also, the quench fields found in three of the cavity tests are compatible with a thermal quench induced by a defect size in the range of 20 µm, which is reasonable given the increasing quality of the available commercial niobium and the cavity preparation processes.

In proof of the above statement we can consider the simple (frequency independent) model for the magnetic field at the occurrence of the quench, H_{max} [6]

$$H_{\max} = \sqrt{\frac{4k_{th}(T_c - T_b)}{aR_n}}$$

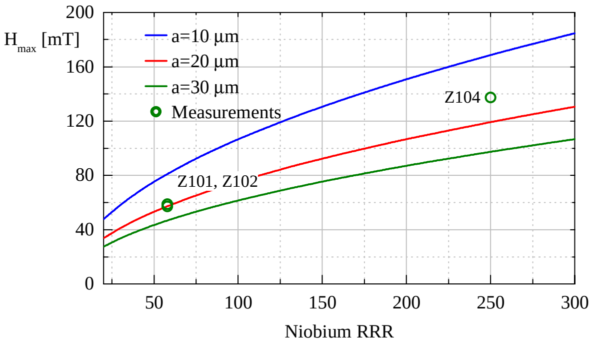

Figure 4: The magnetic surface field at quench from the measurements, compared with the thermal breakdown field from ref. [6]. Solid curves: defect size, *a*, 10 µm, 20 µm and 30 µm (from top to bottom, respectively).

where T_b is the bath temperature, T_c the critical temperature, k_{th} the thermal conductivity of niobium (~RRR/4), a the defect size and R_n the surface resistance of normal conducting niobium (10 mΩ). Figure 4 shows the above relation for a range of defect sizes, and the three experimental points (RRR=58 has been estimated from measurements for the low grade niobium).

4 STATUS OF THE MULTICELL PROTOTYPE CAVITIES

The experience gained in the fabrication and test of the single cells suggested a few changes in the cavity tooling, for the fabrication of two five cell cavities. First, all the tests indicated a frequency offset with respect to the nominal frequency. This offset was due to the action of the tooling used to prepare the half-cells for the weld and resulted in a deformation of the cell shape, confirmed by means of reference shape tests and 3D measurements. A new tooling was manufactured and resulted in not appreciable half-cell deformations on copper samples. As a second change, the cavities are now equipped with TTF-type NbTi welded flanges. The fabrication of the two five-cell cavities equipped with coupler ports and helium vessel flanges has been recently launched.

A facility for the preparation and test of cavities, equipped with a class 100 clean room, a HPR system and a vertical cryostat, has been commissioned in LASA for further tests of the single-cell cavities and for the five-cell cavities measurements.

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