VERTICAL TESTS OF ESS MEDIUM BETA PROTOTYPE CAVITIES AT LASA

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Abstract

In the framework of the INFN activity related to the European Spallation Source collaboration, the LASA infrastructure has been renewed to allow the qualification, in its vertical cryostat, of the 704 MHz medium beta (MB) cavity prototypes. A new cryogenic insert has been realized, fully equipped with dedicated mechanical supports, vacuum, thermal sensors and quench diagnostic systems. The RF test station has been upgraded as well with a new PLL electronics rack. The Medium Beta cavity prototype designed and produced by INFN Milano has been successfully cold tested at 2.0 K temperature, outperforming the ESS specifications. The technical features of LASA infrastructure and the cold tests of the superconducting cavities (SC) are described in this paper.

INTRODUCTION

The Medium beta ($\beta = 0.67$) section of the European Spallation Source (ESS) Linac is composed of 36 six-cell elliptical superconducting (SC) cavities [1]. As a part to the in-kind contribution of Italy to the ESS project, INFN-LASA is in charge of the development and of the industrial production of the whole set of 36 resonators [2]. Two cavity prototypes have been realized with same geometry but different materials, in order to verify all the fabrication and treatment processes for the 36 series Medium beta cavities. One prototype was realized using Fine Grain (FG) Niobium, i.e. the standard technology for SC cavities and the other one using Large Grain (LG) Niobium, to explore the possibilities and potentialities of this material [3]. The Medium beta cavity prototypes have been completely designed by INFN LASA team and built by Ettore Zanon S.p.A, in Schio, under our constant supervision [4].

The FG cavity had been delivered, under vacuum condition, to LASA at the end of October 2017, ready to be tested and qualified at the LASA Vertical Test Facility.

VERTICAL TEST FACILITY

Installation on Insert

The FG cavity (named MB001) installed on the vertical test insert is shown in Fig. 1. The insert top flange hosts all the ports and feedthroughs to connect the instrumentation needed for the test and a pipe to connect the cavity with the vacuum pumps. A Sputter Ionic Pump (SIP) is also permanently installed on the insert top cover. The insert is also equipped with diagnostic devices to monitor the cavity status during the cold test [5].

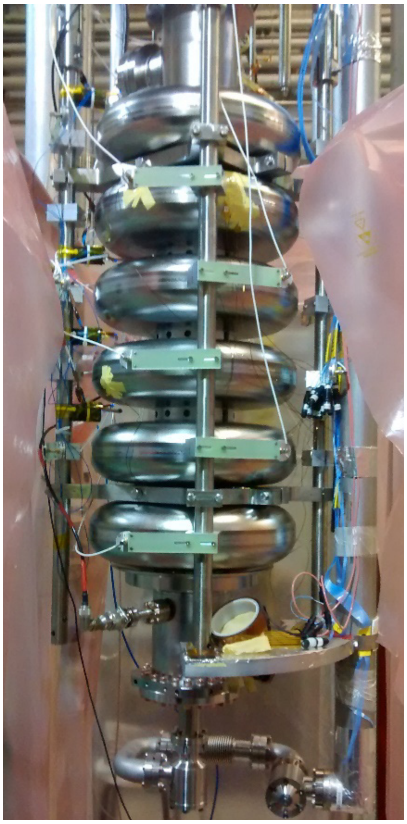

Figure 1: MB001 cavity installation on the insert.

The cavity is first assembled on the vertical insert using a portable clean room to perform the vacuum connection. The insert vacuum line is then slowly pumped and leak checked before switching on the SIP. Only after the vacuum level is below 10^{-5} mbar the cavity valves are opened, after isolating the forevacuum system of the vertical insert line. The warm RF cables are then tested and the cavity frequencies checked before moving the insert into the cryostat.

RF CAVITY CHARACTERIZATION

LASA Vertical Test Facility

A 650 W solid state (mod. L500 UHF) commercial power amplifier from ABE Elettronica [6], whose frequency range is 500 – 900 MHz, feeds the cavity. The amplifier is internally protected by a circulator, allowing full power operation with high SWR ratios and pulsed tests with strong over-coupling. Incident and reflected powers are sampled through a 1:20 power reflectometer. The power is coupled to the cavity by a coaxial antenna

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(High Q Antenna) of nominal $Q_I = 10^{10}$. The power coupler port interface to the power amplifier is through a 7/16 connector and a 1/2" CELLFLEX low-loss foam dielectric coaxial cable. The connector and the cable withstand more than 1 kW RF power at 700 MHz, ensuring safe operation (no cable or connector breakings) also at full reflected power and a low RF loss inside the Helium bath [7]. Nevertheless, we choose to limit the amplifier output power to 250 W, as a redundant safety margin, being this power more than enough to qualify the ESS cavities. A block diagram of the cavity RF measurement system is shown in Fig. 2. Last but not least, a common problem during the cavity tests in vertical cryostats is the breaking of high power RF coaxial feedthroughs for power over 100 W, due to sparking between the outer and inner conductors in He gas. We solved this issue avoiding the use of any commercial feedthrough in the low pressure vapour environment of the cryostat top flange, using a custom-made vacuum-proof solution [8].

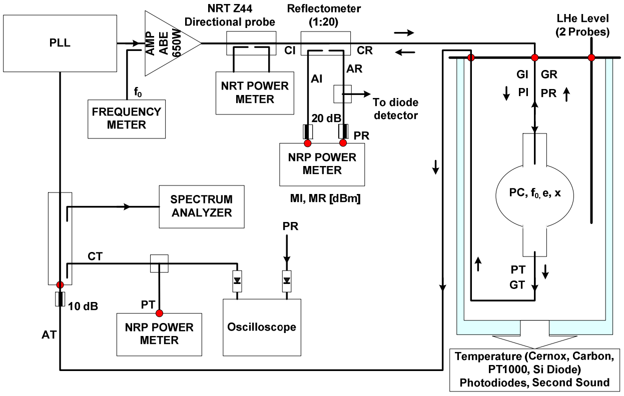

Figure 2: Block diagram of the RF system.

To sample the cavity dissipated power, a pick up antenna (nominal $Q_{ext} = 3 \cdot 10^{11}$) is installed on the cavity beam tube opposite to the main coupler, through a 7/16 connector on a vacuum flange. All cavities transmitted powers are carried out from the cryostat through high screened cryogenic coaxial cables (S_04212_B type from Suhner). Finally 1/4" CELLFLEX coaxial cables with high phase stability, are used to transmit the cavity powers to and from the external electronic devices and instrumentation. The cavity accelerating field and unloaded quality factor (Q_0) are measured through the accurate readings of the input, reflected and transmitted powers, both in CW and pulsed mode. We use NRP2 power meters, from Rohde & Schwarz, provided with NRP-Z11 diode power sensors. The dynamic of these probes is of 90 dB, ensuring us great linearity during the power rise. Normally we stay inside 40 dB of power variation during the cavity characterization. The cavity transmitted and reflected powers are demodulated, when in transient mode, to get the (loaded) discharge time and the input port coupling factor, for computing the proper Q_0 of the cavity at a moderate value of accelerating field, and to determine the calibration constant before the power rise. The coaxial cables that connect the test signals to the readout instrumentation are very accurately calibrated (within some tenth of dB) before starting the test, using both a VNA and a calibrated power source at cavity nominal frequency.

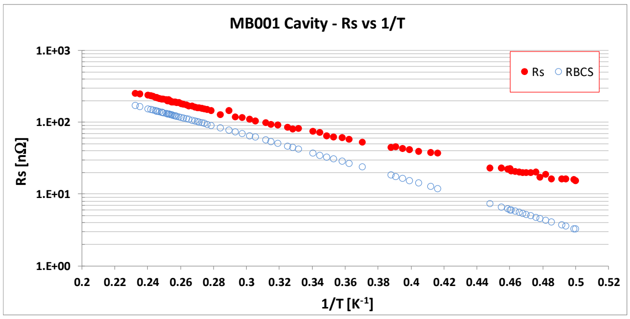

Figure 3: MB001 R_s behaviour during sub-cooling.

Fine Grain Cavity Test

The FG cavity (MB001) was tested in November 2016. Sub-cooling from 4.2 K to 2 K took about 3 hours, as usual. During this operation, we monitored the behaviour of the surface resistance against the bath temperature, performing measurements at moderate field levels (typically between 0.2 and 1 MV/m of accelerating gradient (E_{acc})). At 2K the surface resistance R_s was close to 10 nΩ. The behaviour of the R_s during the subcooling operation is shown in Fig. 3.

The MB001 power test was successful. Fig. 4 shows that the Q_0 versus E_{acc} plots (power rise), of the first MB prototype cavity are well above the ESS requirements of $E_{acc} = 16.7$ MV/m @ $Q_0 > 5 \cdot 10^9$. E_{acc} higher than 22 MV/m (@ $Q_0 > 5 \cdot 10^9$) has been reached and, at ESS goal accelerating gradient, the quality factor was $Q_0 \sim 1.5 \cdot 10^{10}$.

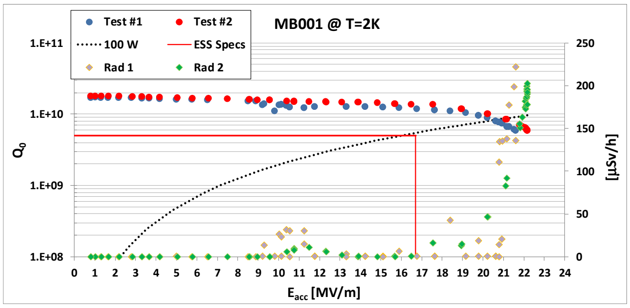

Figure 4: MB001 first test result.

Throughout this first test two power rises were performed. During the former, we found soft multipacting barriers for E_{acc} between 9 and 10 MV/m, as preview by multipacting code simulations [9]. Few minutes of RF processing had been enough to overcome any barrier. During the second power rise, the multipacting has been passed without processing. Field emission (F.E.) has been observed at higher E_{acc} values. The X-ray radiation dose measured was slightly over 200 µSv/h, though some conditioning is evident during the second power rise. During both power rises the cavity began quenching at field over $E_{acc} = 22$ MV/m.

Having passed the qualification test, the MB001 cavity was sent to the factory to be installed inside the He Tank. During this operation the cavity sustained additional final BCP treatment and some HPR cycles. After having passed the pressure tests the cavity has been sent back to LASA to be cold tested again. The MB001 cavity integrated in the He Tank is shown in Fig. 5, just arrived at LASA from Zanon. The cavity with the He Tank repeated the good performances of the naked cavity, as reported in Fig. 6: the cavity outperformed the ESS requirements and quenched again at about E_{acc} = 22 MV/m, with low gradient $Q_0 \sim 2\cdot 10^{10}$. Neither multipacting nor X-ray radiation have been recorded during the second test, evidence that the field emission has been cured by the second cycle of treatments (final BCP + HPR cycles) during the cavity integration. A summary of the MB001 cavity performances (2nd test), compared to the ESS project requirements, is in Table 1.

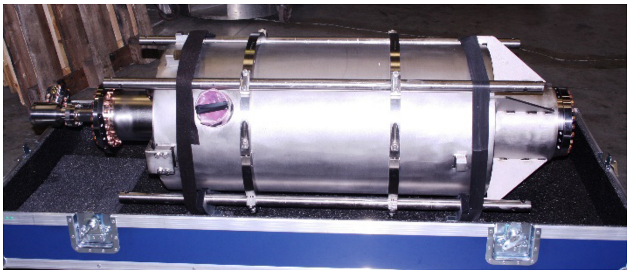

Figure 5: MB001 inside He Tank delivered at LASA.

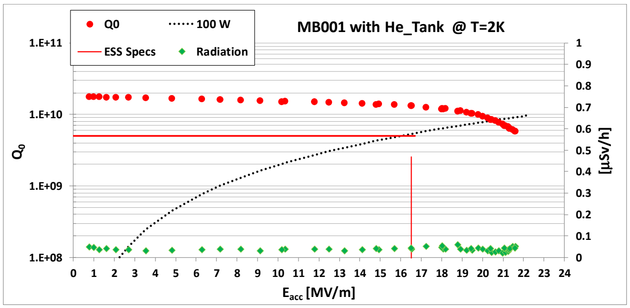

Figure 6: Performances of MB001 with He Tank.

Table 1: MB001 Performances and ESS Requirements

	MB001	ESS Specs
f_π [MHz]	704.213	704.2 ± 0.1
f_π closest f [MHz]	703.449	f_π ± 0.45
Max E_{acc} [MV/m]	21.6	> 16.7
Q_0 @ ESS E_{acc}	$1.3\cdot 10^{10}$	$> 5\cdot 10^{9}$
Q_0 @ Max E_{acc}	$6\cdot 10^{9}$	
Q_I (input Q_{EXT})	$6\cdot 10^{9}$	$1\cdot 10^{10}$
Q_T (PU Q_{EXT})	$9\cdot 10^{10}$	$2\cdot 10^{11}$
F.E.@ Max E_{acc}	0.043 µSv/h[1]	

[1] Note: ground dose level

Large Grain Cavity Test

The large grain medium beta cavity (named MBLG002) test was performed in the second half of December 2016. The cavity received the same preparation processes of the MB001. The Q_0 at low field was again close to $2\cdot 10^{10}$, but the cavity quenched at lower field than expected, as shown in Fig. 7.

Four power rises were executed during the test. In the first one, multipacting barriers were observed around E_{acc} = 9 MV/m. Once these were processed, the cavity quenched at E_{acc} = 9.6 MV/m, far from the ESS specs. In addition, significant F.E. was observed, with X-ray radiation above 1 mSv/h at the maximum E_{acc}, with a peak of 1.8 mSv/h during multipacting processing. As shown in Fig. 8, during the other three power rises, the F.E. has been partially reduced (RF processing), down to less than 1 µSv/h in the 4th power rise, but the accelerating gradient had just a small improvement, reaching E_{acc} = 10.1 MV/m before quenching.

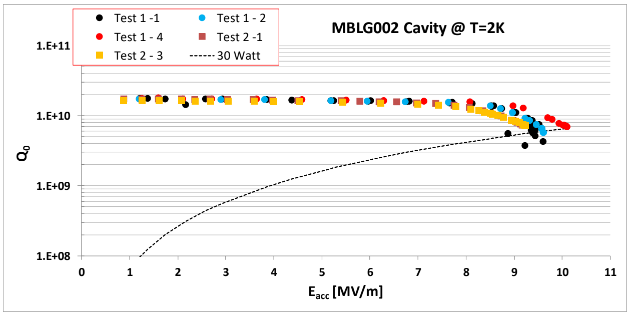

Figure 7: Performances of MBLG002 cavity.

The MBLG002 cavity was sent back to the factory for additional processing, to try to improve gradient performances. After a final BCP and HPR the cavity has been tested again, but without gradient improvements. However, after the re-treatment, no evidence of multipacting has been recorded and the F.E. was measured below the ground dose. For additional information about the large grain cavity, see [3], presented at this conference. Also, for more details about the cavity quenching, refer to [5].

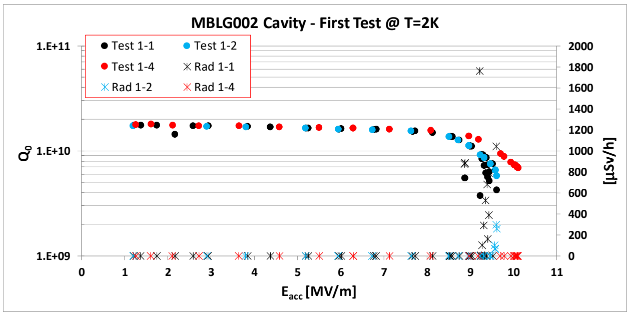

Figure 8: MBLG002 Q_0 vs E_{acc} plots showing F.E.

CONCLUSION

Two MB cavity prototypes have been designed and produced by INFN LASA as a part of the Italian in kind contribution to the ESS project. The fine grain cavity, MB001 outperformed the ESS specs and after integration in its He Tank, is now installed in the ESS Medium Beta section prototype cryomodule (M-ECCTD), together with three other MB cavities produced by CEA Saclay [10]. Furthermore a call for tender for the production of 38 (2 spares) fine grain Nb cavities, based on MB001 design, has just been issued.

The Large Grain Niobium prototype cavity showed good Q_0, but didn't reach yet the ESS requirements for E_{acc}. R&D work on this topic is ongoing.

The full set of results of the MB cavity qualification tests is in [11].

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