FIRST TEST RESULTS OF THE 4-ROD CRAB CAVITY *

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Abstract

The first compact prototype crab cavity with the 4rod geometry has undergone surface treatment and cold testing. Due to the complex geometry and unique fabrication procedure, RF validation of the field at beyond the nominal operating voltage at a sufficiently high Q_0 is an important pre-requisite. Preliminary results of the first cold tests are presented along with cavity performance at different stages of the cavity processing is described.

INTRODUCTION

A 4rod cavity design for the purpose of crab crossing in the LHC upgrade was conceived and prototyped in bulk Niobium [1]. The relevant RF parameters of final cavity design which was prototyped are listed in Table 1. The prototype was built in bulk Niobium with the 4 rods machined from a solid Nb ingot [2] as a proof of principle field validation to the nominal kick voltage and beyond to understand the stability, quench limit of this design. The 4rod cavity was the first compact LHC crab cavity tested up to moderately high surface fields ($\sim$ 16 MV/m). This paper describes the surface preparations and the subsequent cold tests and related observations.

Table 1: Relevant RF parameters of the 4rod crab cavity.

	Unit	Value
Frequency	[MHz]	400.79
Nearest Mode	[MHz]	373
V_T	[MV]	3.3
R/Q	[Ω]	915
E_{pk}	[MV/m]	35
B_{pk}	[mT]	67
Stored Energy	[J]	7.4
Geometry Factor	[Ω]	63

CAVITY SURFACE PREPARATION

Due to the complexity of the structure and lack of sufficient experience with electron discharge machined (EDM) Niobium, a significant amount of material was removed. This is primarily required to remove oxidation and defects induced during the machining process. The first buffer chemical polishing (BCP) to remove approximately 150 μm was performed at Niowave Inc. [3]. The standard chemical mixture using vertical insert (see Fig. 1) with a rotational mechanism to ensure uniform removal of material. The cavity acid flow rate was controlled to 0.32 l/sec and subsequently reduced to 0.13 l/sec for a slower removal rate. The cavity was cooled with external chiller sprayed on to the surface acting a heat exchanger with temperature kept between 5-9 °C. The cavity was rinsed with ultra clean water and checked for leak tightness to about 10^{-10} mbar. A high temperature bake of the cavity typically performed for hydrogen degassing for SRF cavity was performed at CERN. The baking was performed in a UHV furnace at approximately 600-650 °C for at least 48 hrs. The pressure reached approximately 3.5×10^{-7} mbar at 650 °C corresponding to a Hydrogen concentration of about 2.5 ppm. Fig. 1 shows the 4-rod crab cavity in the CERN UHV vacuum furnace [4].

The final light chemistry to remove any after the high temperature bake was not performed due to time constraints. This step is typically required as the Niobium surface gets strongly reactive beyond 380°C allowing impurities to steadily diffuse into the Niobium bulk [4]. This step being presently being prepared for before subsequent cavity tests in the vertical cryostat. A high pressure rinsing

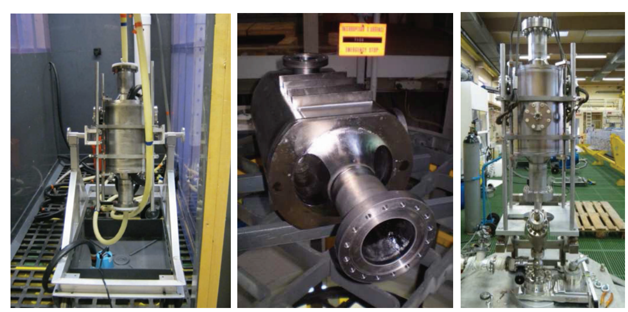

Figure 1: Left: Vertical BCP setup for heavy etching of the cavity surface (Courtesy Niowave Inc.). Middle: 4rod crab cavity preparation for the high temperature bake in UHV furnace. Right: High pressure water rinse setup at CERN.

(HPWR) of the cavity is now a standard procedure to remove any foreign material (or field emitters) on the surface that enhance the field locally in the high field region. A HPWR was performed with the CERN setup (see Fig. 1). Fig. 2 shows the measured total organic content (TOC) and the resistivity of water reaching approximately 17 MΩ.cm over a period of 2 hrs. The particle count for sizes less than 1μm remained high ($> 7 \times 10^4$), but particles above 0.2-1 μm reached well below 3000-20 respectively with a strong attenuation of overall fluctuations in the TOC.

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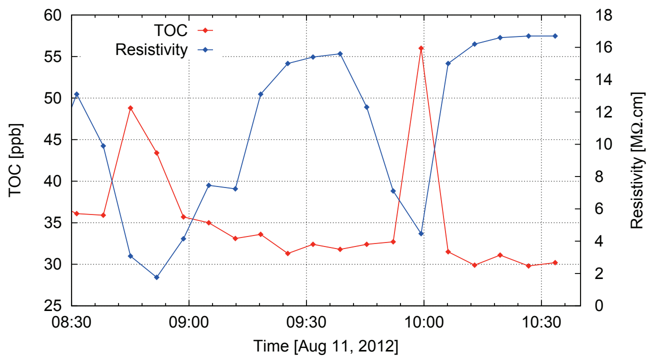

Figure 2: Total organic content and resistivity of the water during the high pressure water rinsing of the cavity.

CAVITY COOLDOWN

The cavity was first cooled down from room temperature to 4.5 K. The cool down rate in the typical zone spanning 50-150 K was maintained to over 2 K/min to avoid the well know Q-disease at low-fields. Fig. 3 shows the temperature profile during the first cool down where the different curves indicate the different temperature monitors on the test cryostat.

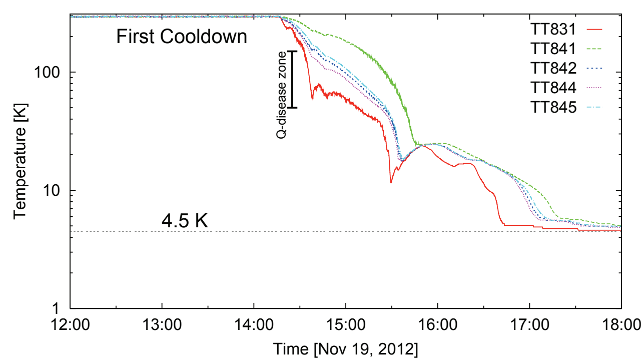

Figure 3: Temperature evolution during the first cool down of the 4Rod crab cavity.

During the cool down, the cavity pressure reached as high as 10^{-2} mbar due to a leak. The turbo pump was always kept active to reduce the pressure to 10^{-5} mbar. Due to an error in cool down sequence, the external magnetic field compensation was not activated. Therefore a warm-up beyond the critical temperature to 20 K was performed to activate the field compensation. However, no significant change in the cavity pressure was observed after the warm-up and cool down procedure. Following some initial RF measurements at 4.5 K, the cavity was cooled down to 2 K in two steps to have a sufficient liquid level in the short cryostat to immerse the cavity. Fig. 4 shows the temperature and pressure evolution during the cool down to 2 K. The pressure at 2 K was reduced to approximately 10^{-7} mbar but still quite high compared to typical vacuum levels during vertical tests. RF measurements were performed despite the bad vacuum which are discussed in the following section.

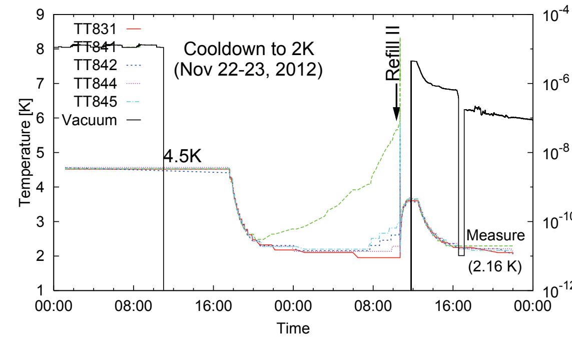

Figure 4: Temperature evolution during the cool down of the 4Rod crab cavity to 2 K. A Helium refill was necessary to maintain sufficient liquid level in the short cryostat.

The Helium liquid level was varied at 2 K by a controlled heater to potentially identify the location of the leak. However, only a gradual (see Fig. 5) change in the pressure was observed as a function of the liquid level leading to no inconclusive results. During the warm up procedure, the pressure remained high. Fig. 5 also shows the temperature and cavity pressure during the warm up procedure. Increase in cavity pressure up to 10^{-5} mbar similar to before was observed with some small steps above transition temperature of the cavity.

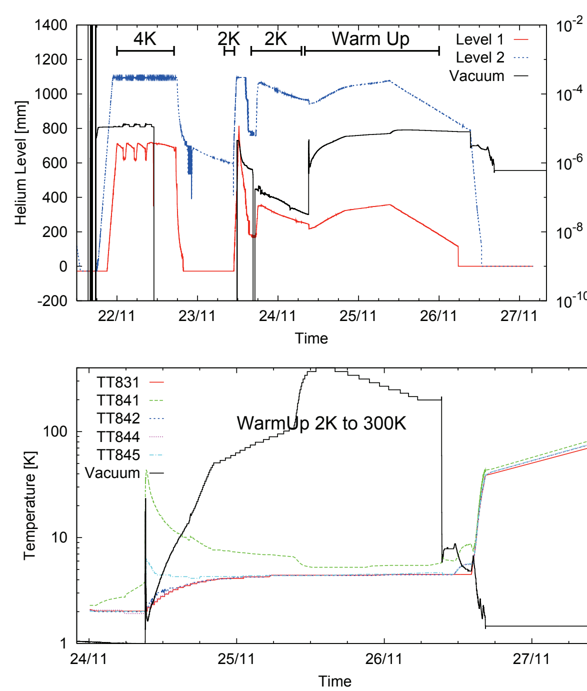

Figure 5: Helium liquid level (top) and temperature evolution (bottom) at 2 K and the warm up of the cavity.

RF MEASUREMENTS

The input and pickup probes were installed according to Fig. 6 on the top and side respectively. The input probe length was numerically calculated to reach a $Q_{ext} = 10^8$ and therefore require input power of approximately 100 W to reach the nominal voltage of 3.3 MV. A L-shaped hook was used for the pickup probe due to obtain sufficient coupling ($Q_{ext} \approx 0.5 - 1.0 \times 10^{11}$) to the dipole mode due to the location of the port.

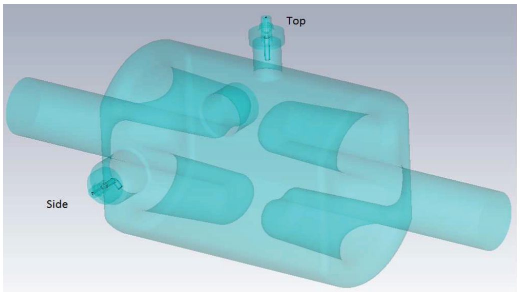

Figure 6: Input and pickup probe configuration for appropriate coupling required in the vertical tests.

The BCS resistance at 400 MHz at 4.5 K and 2 K are about 63 nΩ and 1.6 nΩ respectively. RF measurements both at 4.5 K and 2 K indicate similar residual resistance of about 90-100nΩ. Fig. 7 shows the Q_0 as a function of the deflecting voltage for measurements at 2.12 K using the standard incident/reflected/transmitted power technique. The different series correspond to subsequent mea-

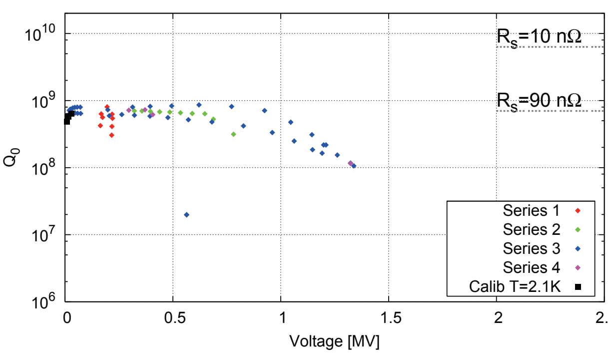

Figure 7: Measured cavity quality factor as a function of deflecting voltage in the cavity.

surements with increase in the incident power as the cavity was conditioned gradually from its virgin state. Ultimately, the transverse voltage was limited to approximately 1.35 MV where strong multipactor like activity was observed and sufficient time was not available to further condition the surface. This barrier could have also resulted from the bad vacuum conditions. For the final series, a Q_0 measurements with decreasing incident power was performed which revealed a small hysteresis like effect. A few calibration points from the emitted power decay were taken as a reference, but were not repeated at higher field levels. Only a minor amount of radiation was observed even at the highest field value.

Following the inconclusive results in the vertical test cryostat, a leak test of all flanges and all joints were carried out by cooling with LN_2 and simultaneously injecting Helium gas. This procedure revealed one of the unused flanges on the side port located on the cavity body to produce a pressure increase, but not at the level seen inside the vertical test cryostat. A closer visual inspection of the knife edge on these special NbTi flanges revealed an rather uneven edge which could potentially lead to a leak at cryogenic temperatures. A resurfacing of the knife edges is being performed before future tests can commence [5]. The

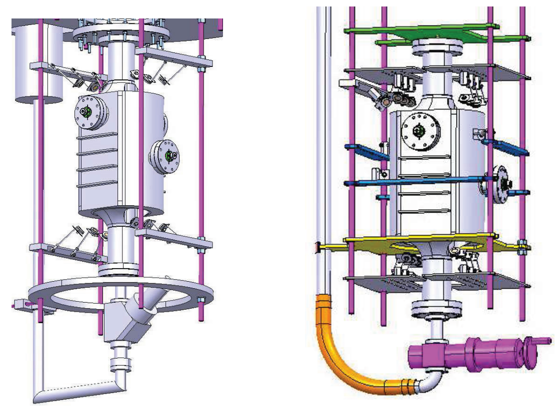

Figure 8: 4rod cavity integration layout for first cold RF measurements (left) and subsequent modification (right).

cavity insert used for integration into the vertical cryostat (see Fig. 8) also revealed some improper stress points on the cavity which have been carefully analyzed. Modifications to the insert are implemented (see Fig. 8) to attain minimal stress on the cavity for future tests [6].

DISCUSSION

The 4rod cavity was the first compact crab cavity which reached approximately half the nominal kick voltage with moderately high surface fields. The measured low field Q_0 factor corresponds about 90 nΩ where the theoretically expected value is about 10 nΩ. However, at higher fields, the Q_0 dropped by a factor of 10. The lack of a final light chemistry after the UHV bake and the rather significant vacuum leak are likely to have contributed to the observed performance. Nevertheless, these first measurements indicate a rather good performance given the complex fabrication procedure and the setback in cavity preparation.

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