

# FIRST RF PERFORMANCE RESULTS FOR THE DQW CRAB CAVITIES TO BE TESTED IN THE CERN SPS \*

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## Abstract

As part of the High Luminosity LHC (HL-LHC) project strategy, crab cavity correctors shall be installed around CMS and ATLAS experiments of the LHC. To accommodate the different crossing angle planes, two distinct cavity designs have been selected: the RF Dipole (RFD) and the Double Quarter Wave resonator (DQW). CERN has fabricated two double quarter wave resonators (DQW\_SPS), for validation with a proton beam at the CERN SPS accelerator. Standard superconducting rf surface preparation protocols have been applied to the two bulk niobium cavities, followed by cryogenic testing in a vertical cryostat at CERN's SM18 facility. The performance results obtained after the first bare cavity tests for cavities DQW\_SPS\_001 and DQW\_SPS\_002 are shown in this paper, and include  $Q_0$  vs  $V_T$  curves, Lorentz Force Detuning (LFD) analyses and pressure sensitivity of a higher order mode.

## INTRODUCTION

To ensure safe and effective operation of the crab cavities in the upgraded LHC, it is essential to validate such cavities with hadron beams. For this reason, a first beam test has been foreseen in the SPS for 2018 [1]. For this test, two cavities of the DQW design have been produced *in-house* at CERN, and are soon to be assembled into a two-cavity cryomodule.

Exhaustive work was done to optimise the electromagnetic and mechanical design of the DQW in order to evolve from the Proof-of-Principles (DQW\_PoP) to the DQW\_SPS series [2]. Tight fabrication procedures were followed to produce two bulk niobium cavities, namely: DQW\_SPS\_001 and DQW\_SPS\_002 [3,4] (see Fig. 1)\*. The cavities underwent a standard Buffered Chemical Polishing (BCP) surface treatment prior to their vertical cryogenic test, as part of their validation for cryomodule assembly.

The SM18 vertical cryostat setup allows powering up to 250 W, with a standard operating temperature of 1.8 K. Full environmental monitoring data is recorded throughout the cool down, rf operations, and controlled thermal cycles or warming up of the cavity. This, for example, allows for helium bath pressure and thermal fluctuation corrections to the rf cavity performance, and to extract information of the

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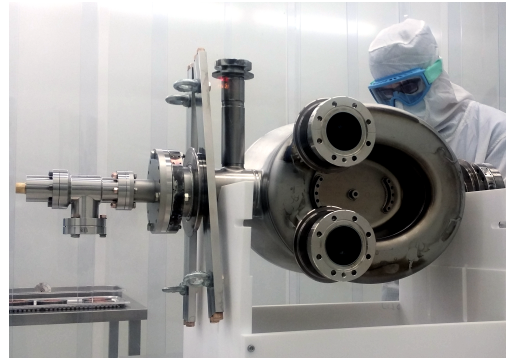


Figure 1: One of the two DQW\_SPS crab cavities during clean room assembly (ISO4).

cavity's surface properties. We will present, in the following sections of this paper, the full description of the experimental setup, as well as determination of cavity material properties.

## SURFACE PREPARATION AND EXPERIMENTAL SETUP

After fabrication, the two cavities followed a surface preparation protocol that includes surface chemical etching, thermal treatment (650 °CC) in a vacuum oven, and High Pressure Rinsing (HPR). The diagrammatic workflow of the surface treatment and testing is presented in Fig. 2.

### High Pressure Rinsing

The HPR was done using a vertical 100 bar cabinet with a di-jet nozzle. Rinses were performed in cycles, with a vertical nozzle speed of 0.2 mm/s, and a cavity rotation of 3 RPM. Rinsing time is approximately 65 hours total per cavity, which is considerably longer than the standard, but is determined by the quality of the waste water sampled from the HPR. Despite this excessive rinsing time, we have found that this approach brings the best results in terms of surface cleanliness and rf performance. Figure 3 shows the difference in the particle counts and total organic content (TOC), between the first rinse (left) and the last rinse (left), for both cavities.

### Vertical Test Setup

In general, both the insert and cryostat are furnished with diagnostics to provide local and ambient insights on the conditions at which the cavities are subject during thermal

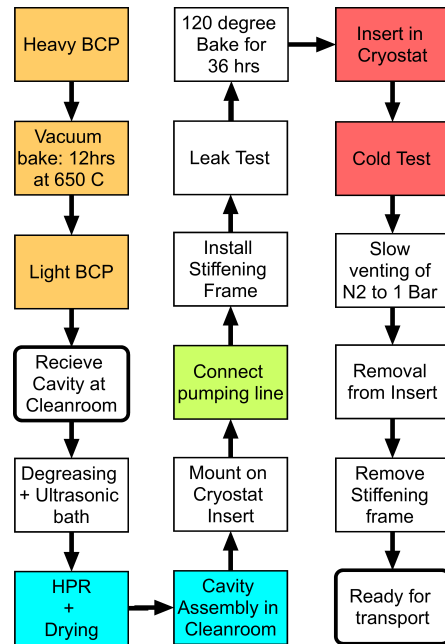


Figure 2: Schematic cavity preparation and testing sequence. The colour code of the activities is: Green = ISO5 environment, cyan = ISO4 environment, red = cryostat operation from 300K to 2K, orange = chemistry facility.

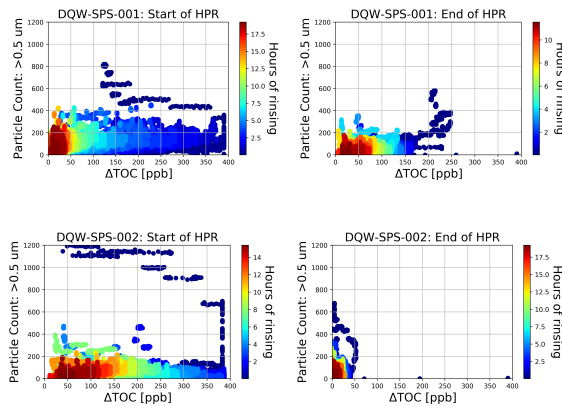


Figure 3: Water monitoring of the first and last rinses for both cavities.

cycling and powering. The diagnostics deployed on the cavities for the vertical test include: contact CERNOX temperature sensors for temperature mapping, single-axis magnetic flux probes for ambient field measurements, four-wire measurements for in-situ bulk-Residual Resistance Ratio (RRR) measurements, and an array of Oscillating Superleak Transducers (OST) for quench detection. This instrumentation is in addition to the aforementioned environmental monitoring of the cavity vacuum and Helium bath pressure, as well as heaters for controlling the thermal gradient across the cavity and cryostat warm up [5].

## CAVITY PERFORMANCE

Both cavities were tested at 1.9 K with an average cool down rate of 20 K/min. Also, both cavities systematically presented multipacting at low transverse voltages (i.e. 0.25 MV). These barriers required some rf conditioning using amplitude modulation for several hours to allow stable conditions for decay time and power calibration measurements.

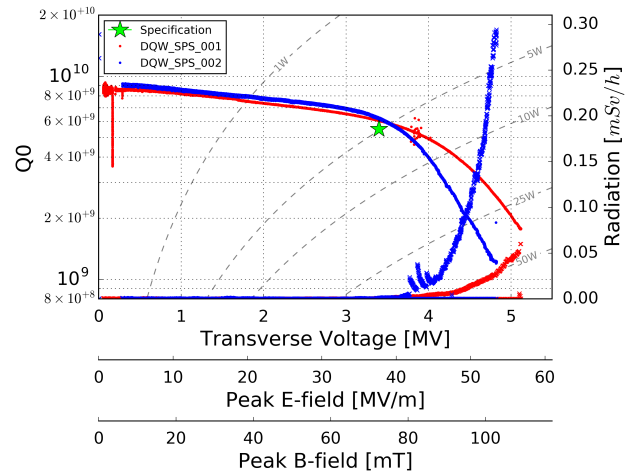


Figure 4: First performance results (at 1.9 K) for the DQW crab cavities to be installed the SPS test.

### First Cavity (DQW\_SPS\_001)

From the  $Q_0$ -curve in Fig. 4 a low level multipacting barrier at  $V_T \approx 0.25$  MV is clearly visible for DQW\_SPS\_001. With a cavity geometry factor of 87, the low field  $Q_0$  value indicates a residual resistance  $R_S = 10$  n $\Omega$ , while the curve presents a moderate slope as it increase in transverse field. The dynamic load at the operating voltage is lower than 5 W. The field emission onset starts above  $V_T = 4$  MV, reaching relatively low radiation levels ( $\sim 50$   $\mu$ Sv/h) before quenching. At the quench limit, the cavity reached a maximum transverse voltage of  $V_T = 5$  MV, and maximum peak fields of  $E_{peak} = 56$  MV/m and  $B_{peak} = 109$  mT.

### Second Cavity (DQW\_SPS\_002)

Similarly, from the  $Q_0$ -curve in Fig. 4, it can be seen that the second cavity scan was intentionally started above the multipacting barrier at  $V_T \approx 0.25$  MV level. Still, the low field  $Q_0$  value shows a slightly lower residual resistance of  $R_{Res} = 9$  n $\Omega$ , and the midfield Q-slope is similar to that of DQW\_SPS\_001. Similarly, the dynamic load at the operating voltage is lower than 5 W. Field emission onset starts earlier in this cavity, at about  $V_T = 3.5$  MV, reaching also higher radiation levels before quenching ( $\sim 300$   $\mu$ Sv/h), the high field Q-slope is therefore more abrupt due to the field emission. The cavity will be further processed to push the field emission onset to a higher level and try to reduce the amount of radiation to similar levels than for DQW\_SPS\_001. At the quench limit quench, this cavity reached a maximum trans-

verse voltage of  $V_T = 4.8$  MV, and maximum peak fields of  $E_{\text{peak}} = 54$  MV/m and  $B_{\text{peak}} = 103$  mT.

## SURFACE RESISTANCE

The surface resistance  $R_S$  was calculated by monitoring of the cavity quality factor during warm up at a fixed field level, and fitting it to the BCS surface resistance. In this way, we can get an estimation of the residual resistance. Figure 5 shows the data obtained for cavity DQW\_SPS\_001, where the residual resistance was estimated to be  $R_{\text{Res}} = 10.0$  n $\Omega$ .

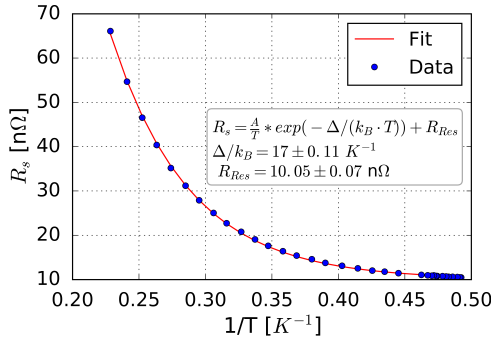


Figure 5: Surface resistance data fitting for cavity 001.

## LORENTZ FORCE DETUNING

Real time estimation of the Lorentz Force Detuning (LFD) is possible due to precision tracking of the frequency during powering scans. The frequency shift ( $\Delta f$ ) of the cavity due to the mechanical deformation of the walls from radiation pressure generated by the RF fields, with the is measured and fitted to the known function  $\Delta f \propto K_L V_T^2$ , where  $K_L$  is the *Detuning Constant* in Hz/MV<sup>2</sup> (see Fig. 6).

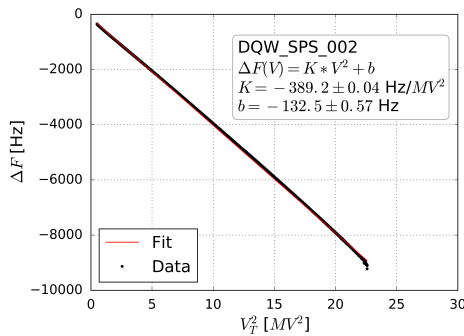


Figure 6: Lorentz Force Detuning data fitting for cavity 002.

The detuning constant were found to be  $K_L = -353.3 \text{ Hz}/(\text{MV})^2$  for DQW\_SPS\_001 and  $K_L = -389.2 \text{ Hz}/(\text{MV})^2$  for DQW\_SPS\_002. These values may differ between each other due to differences in cavity stiffening frame assembly, as the stiffening frame was designed to emulate the stiffening action of the Helium-tank (without tuner). However, as dressed cavities have not yet been measured, comparison of LFD coefficients between bare and dressed cavities (with tuner) is still to be done.

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## PRESSURE SENSITIVITY

During the purge of the cryostat at 300 K—prior to cool down—we followed the peak frequency of one of the higher order modes (1.8 GHz) that has a good coupling at 300 K, to estimate the pressure sensitivity ( $k_P$ ) of the cavity with the stiffening frame. Figure 7 shows the fitting to the data for the 1.8 GHz mode.

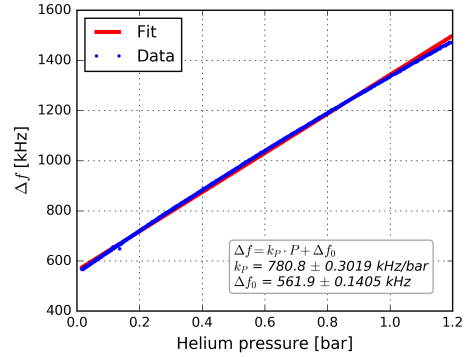


Figure 7: DQW\_SPS\_002 bare cavity with stiffening frame's pressure sensitivity for the 1.8 GHz mode.

## CONCLUSION

The two crab cavities for the CERN-SPS test have been processed and validated successfully. The summary of the first results for both cavities are presented in Table 1.

Table 1: First Test Results of the CERN-SPS Crab Cavities

Cavity	$R_{\text{Res}}$ [n $\Omega$ ]	FE onset [MV]	$V_{T, \text{max}}$ [MV]	$E_{\text{peak, max}}$ [MV/m]	$B_{\text{peak, max}}$ [mT]
DQW_SPS_001	10	4	5.1	56	109
DQW_SPS_002	9	3.5	4.8	54	103

at  $T = 1.9$  K

This work was supported by the upgrades recently performed at CERN for the preparation of superconducting rf cavities, infrastructure, handling protocols, and cleaning procedures.

The monitoring of higher order modes, in particular the 1.8 GHz mode, has proven to be helpful during several steps of the vertical test, such as mounting of the stiffening frame. However, the values measured during these steps—like the pressure sensitivity—must be taken with care, since they are not necessarily representative of the dressed cavity with tuner or the operation conditions for the cryomodule, but are merely an useful tool during testing and preparation.

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07 Accelerator Technology

T07 Superconducting RF

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