MEASUREMENTS ON THE SUPERCONDUCTING 217 MHz CH CAVITY DURING THE MANUFACTURING PHASE*

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Abstract

Since in future the existing UNILAC (Universal Linear Accelerator) will be used as an injector for the FAIR (Facility for Antiproton and Ion Research) project, a new superconducting (sc) continuous wave (cw) linac at GSI is proposed to keep the Super Heavy Element (SHE) program at a competitive high level. In this context, a sc 217 MHz crossbar-H-mode (CH) cavity [1] has been designed at the Institute for Applied Physics (IAP), Frankfurt University, and was built at Research Instruments (RI) GmbH, Germany. The cavity serves as a first prototype to demonstrate the reliable operability under a realistic accelerator environment and its successful beam operation will be a milestone on the way to the new linac. In this contribution measurements during the production process of the cavity as well as corresponding simulations will be presented.

INTRODUCTION

Presently, the fabrication of the sc 217 MHz CH cavity [2] (see Fig. 1) is finished except for the helium vessel. The cavity has a design gradient of 5.5 MV/m which will be achieved by 15 equidistant accelerating cells at an effective length of 612 mm. It is equipped with nine static and three dynamic frequency tuners, a 10 kW cw power coupler and several flanges for surface preparation. The related beam dynamics concept is based on EQUUS (EQUidistant mUlti-gap Structure) [3]. Presently, the cavity is prepared for the high pressure rinsing (HPR) process. Hence, first performance tests on the cavity at 4 K with low rf power are expected at the end of 2015. Since the cavity consists of niobium sheets with 4 mm wall thickness its resonace frequency is very sensitive to external influences. Already small mechanical deformations can change the frequency of the cavity significantly. Static changes of the cavity's resonance frequency will be caused by the manufacturing accuracy, the evacuation process and the cool-down procedure to 4 K. These effects have to be compensated by the static tuners during the production phase. On the other hand, dynamic frequency changes during the operation can be adjusted accordingly by the dynamic tuning system of the cavity [4]. Several measurements have been performed

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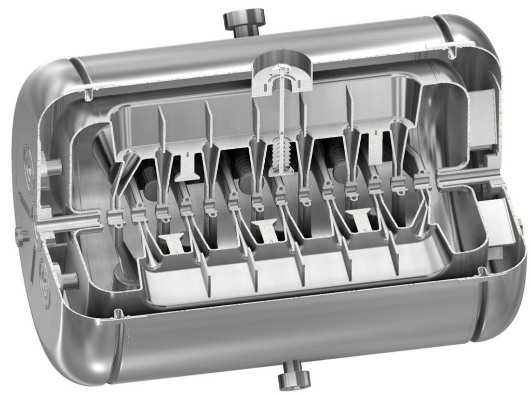

Figure 1: Layout of the sc 217 MHz CH cavity.

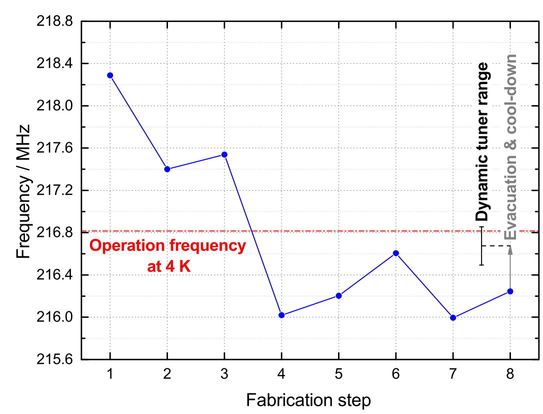

Figure 2: Measured frequency of the sc 217 MHz CH cavity during each fabrication step: (1) temporarily attached end caps with oversize, (2) four static tuners welded in, (3) left end cap welded on, (4) three static tuners welded in, (5) right end cap welded on, (6) 50 μm BCP, (7) two static tuners welded in, (8) 25 μm BCP.

during each fabrication step in order to compensate static variations, thus the frequency of the cavity is finally in the range of the dynamic tuners which provide ±180 kHz/mm (see Fig. 2). Initially, the frequency was designed higher than the operating value and lowered successively by reducing the end cap length, inserting static tuners and by preparing the cavity's surface with standard BCP (Buffered Chemical Polishing) treatment. In principle, an additional BCP

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of 25 μm could be performed after the HPR preparation to improve the performance of the cavity without leaving the operational frequency range.

EVACUATION PROCESS

In order to estimate the cavity's resonance frequency change caused by the evacuation process, coupled structural - high frequency electromagnetic simulations [5] have been performed. By choosing the girders of the cavity as a fixed support and using 1 bar of pressure as an applied load on the surface of the cavity walls, a realistic mechanical behaviour of a self-supporting cavity during the evacuation procedure could be simulated. As shown by Figure 3 (left), the related deformations appear mainly at the center region of the cavity walls and at the end caps which are the most flexible part. The maximum displacement at the end caps is 0.23 mm while the deformation at the walls is about 0.17 mm. As a result of this, the resonance frequency of the cavity increases which leads finally to a pressure sensitivity of 38 Hz/mbar. Considering the influence of the relative permittivity ϵ_r during evacuation, the frequency is increased further by 64 kHz to a total shift of 102 kHz. Figure 3 (right) represents the appearing von Mises stress of the cavity due to 1 bar pressure difference. The maximum material stress was found to be 30 MPa and is located at the end caps. This is still acceptable in comparison to the yield stress of niobium at room temperature (70 MPa). Higher peaks of up to 180 MPa at the stiffening ribs between the girders arise from a singularity of the mesh and can be neglected. The described simulation results have been verified by appropriate measurements. Therefore the deformation of the flexible elements was estimated under evacuation at room temperature with probe indicators while the related frequency shift was recorded. In Figure 4 (top) the measured displacement of the cavity wall due to 1 bar pressure difference is shown. Here the maximum deformation is about 0.14 mm which corresponds to the simulation very well (see Table 1). After ventilation a hysteresis effect due to the deformation of the walls can be noted because the material was still under mechanical tension at that time. The related measured frequency shift shows also a hysteresis whether the cavity is evacuated or ventilated (see Fig. 4 bottom). A total frequency shift of 113 kHz, which is 11 % higher than expected from the simulation, was measured and subsequently compensated with the static tuners during the completion of the cavity. Regarding a realistic operation environment further attachments like the support frame may stiffen the cavity additionally, which will lead to a slightly smaller frequency shift.

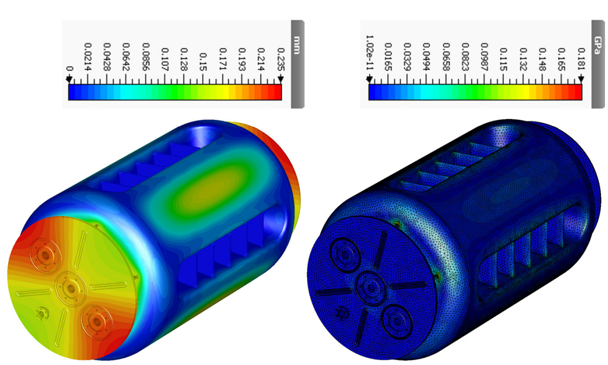

Figure 3: Maximum deformation (left) and von Mises stress (right) of the cavity due to the evacuation process [6].

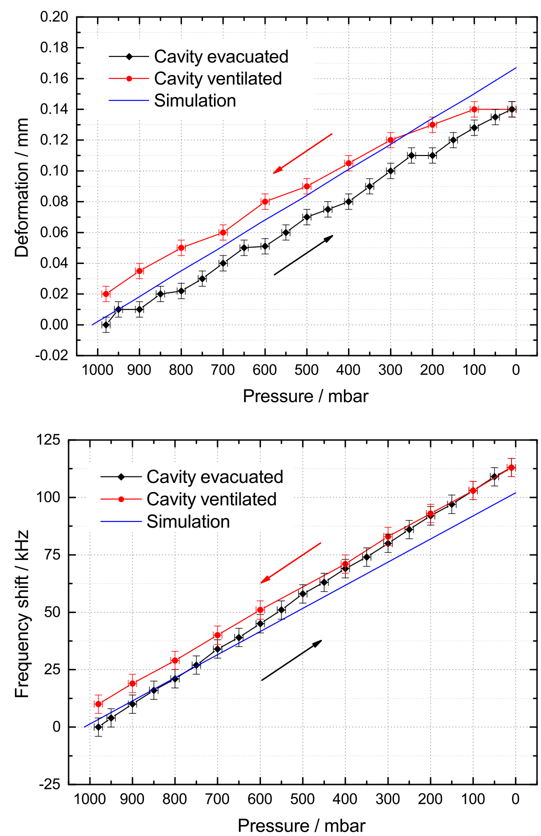

Figure 4: Measured deformation of the cavity wall (top) and related frequency shift (bottom) due to evacuation [6].

Table 1: The 217 MHz CH Cavity Under Evacuation

Evacuation	Simulated	Measured
Deformation end cap / mm	0.23	0.35
Deformation wall / mm	0.17	0.14
Max. stress / MPa	30	–
Δf (incl. ϵ_r) / kHz	102	113
df/dp / Hz/mbar	38	49

COOL-DOWN PROCEDURE

The thermal shrinkage and the related frequency shift caused by cooling down the cavity has been analytically estimated by the total linear contraction ($\Delta L/L = (L_{293\,\mathrm{K}} - L_{4\,\mathrm{K}})/L_{293\,\mathrm{K}} = \Delta f/f$) from room temperature to the indicated temperature. Therefore, the thermal contraction data for niobium at different temperatures was taken from literature [7]. Based on these calculations the cavity shrinks

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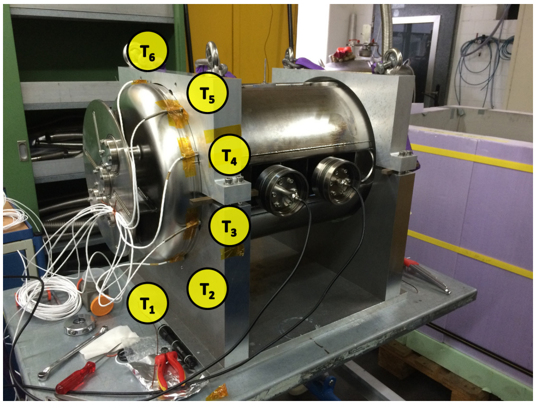

Figure 5: Setup with six temperature sensors to measure the frequency shift during the cool-down with LN_2.

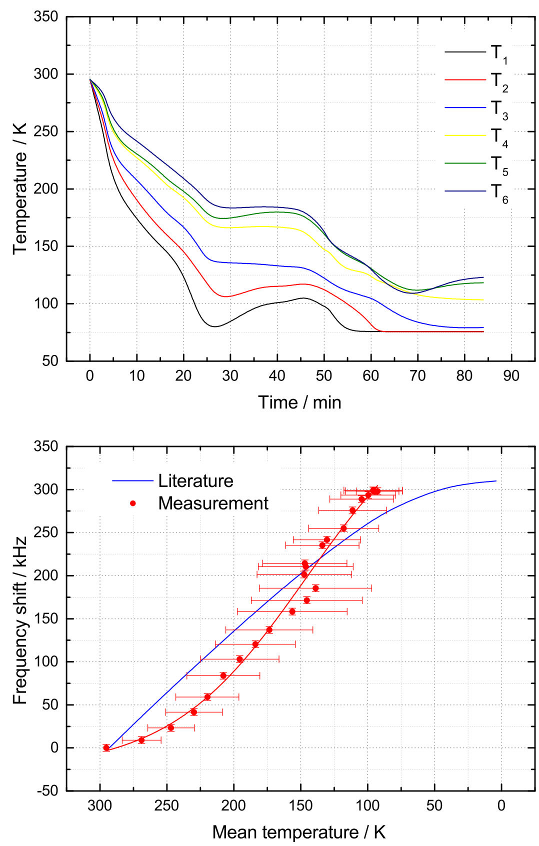

Figure 6: Measured temperature of six probes (top) and related frequency shift (bottom) under cool-down with LN_2.

after cooling down to 4 K about 1 mm in longitudinal and 0.6 mm in transverse direction which leads to a 310 kHz (0.14 %) increase in frequency. Prior to the final assembly the cavity has been evacuated and cooled down with LN_2 while the remaining tuner ports were temporarily sealed with rings made from teflon to validate the expected behaviour. Six temperature probes (T_1–T_6) have been attached along one end cap of the cavity as shown in Figure 5. This setup allowed a measurement of the resonance frequency shift down to a mean temperature of roughly 93 K. Since the cavity was not entirely covered with liquid nitrogen because of a vacuum leakage, a lower temperature could not be reached and the fill operation had to be stopped prematurely. Figure 6 shows the measured temperatures of the sensors as well as the related frequency shift in comparison with the mentioned assumption during the cool-down of the cavity. A total frequency shift of 298 kHz was measured whereas the corresponding estimated value is 268 kHz which matches with the expectations very well. As a final assembling step the estimated frequency shift was compensated with the last two static tuners.

SUMMARY & OUTLOOK

The production of the sc 217 MHz CH cavity is finished except for HPR treatment and the helium vessel. Several simulations have been carried out and validated by appropriate measurements during each fabrication step to analyse the cavity's behaviour considering different external influences. The performed measurements confirm the simulations and assumptions very well and the cavity's operating frequency could be reached within the range of the dynamic tuners. After the surface preparation the cavity will be delivered to the IAP for conditioning and first performance tests with low rf power. This is foreseen for the end of 2015. An additional BCP treatment of 25 μm could be done afterwards to improve the performance of the cavity without leaving the operational frequency range.

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