FIRST PERFORMANCE TEST ON THE SUPERCONDUCTING 217 MHz CH CAVITY AT 4.2 K*

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Abstract

At the Institute for Applied Physics (IAP) of Frankfurt University a superconducting (sc) 217 MHz Crossbar-H-mode (CH) cavity [1] with 15 accelerating cells and a gradient of 5.5 MV/m has been designed. The cavity is the key component of the demonstrator project at GSI which is the first stage to a new sc continuous wave (cw) linac for the production of Super Heavy Elements (SHE) in the future. A successful and reliable beam operation of this first prototype will be a milestone on the way to the proposed linac. After fabrication at Research Instruments (RI) GmbH, Germany, the cavity without helium vessel has been commissioned at the new cryogenic test facility of the IAP with low level rf power at 4.2 K. The results of this first cold test will be presented in this contribution.

INTRODUCTION

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 dedicated sc cw linac at GSI is proposed to keep the SHE program at an international high level. In this context, a sc 217 MHz CH cavity [2] (see Fig. 1) consisting of 15 accelerating cells, with $\beta = 0.059$ and an effective length of 612 mm (see Tab. 1) has been designed which serves as a first prototype to demonstrate its reliable operability under a realistic accelerator environment. Additionally, the cavity is equipped with nine static and three dynamic tuners to compensate frequency changes caused by manufacturing accuracy during the production phase or to adjust the frequency accordingly during operation [4]. Several flanges in each quadrant of the cavity allow an adequate surface processing. For future beam tests, the cavity will be fed with a 5 kW cw power coupler which is currently ready for rf conditioning. The beam dynamics layout of the cavity is based on the special EQUUS (EQUidistant mUlti-gap Structure) [3] concept. Nevertheless, after latest surface preparation steps the new cavity has been extensivley tested with low level rf power at 4.2 K. Afterwards, a helium vessel made from titanium was welded to the cavity to provide a closed helium circulation.

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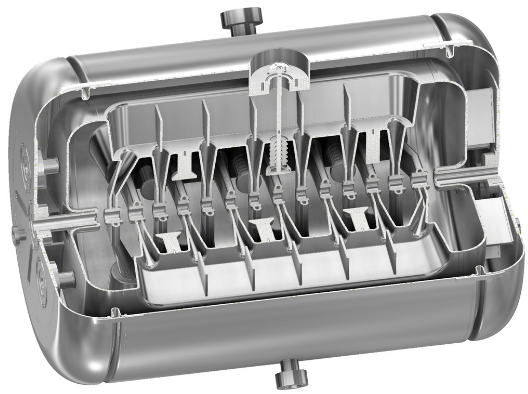

Figure 1: 3D model of the sc 217 MHz CH cavity.

Table 1: Main Parameters of the Cavity

β		0.059
Frequency	MHz	216.816
Accelerating cells		15
Effective length ($\beta\lambda$)	mm	612
Diameter	mm	409
Tube aperture	mm	18 / 20
G	Ω	52
R_a/Q_0		3240
$R_a R_S$	kΩ^2	168
E_a (design)	MV/m	5.5
E_p/E_a		6.3
B_p/E_a	mT/(MV/m)	5.7

EXPERIMENTAL SETUP

At the experimental hall of the IAP a new cryogenic laboratory has been installed for various test purposes of different sc CH cavities allowing performance measurements with low level rf power at 4.2 K and 2.1 K, respectively. The sc 217 MHz cavity was tested at 4.2 K in a vertical cryostat which is surrounded by a radiation cave (see Fig. 2). During the cold test the helium gas was collected by a recovery system. A 50 W broadband amplifier delivered the forward power to the cavity. Further equipment like the rf generator, the rf control system, scopes, power meter, a network analyzer, a piezo amplifier and a spectrum analyzer was arranged in four racks on top of the radiation cave. As shown by Figure 3, the cavity has been provided with seven temperature probes and 60 Thermo-Luminescence-Dosimeter

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(TLD) to record field emission events. Additionally, a piezo actuator and a piezo sensor were used to analyze the mechanical behavior of the cavity and microphonics, respectively.

Figure 2: Setup of the cryogenic infrastructure inside the radiation cave.

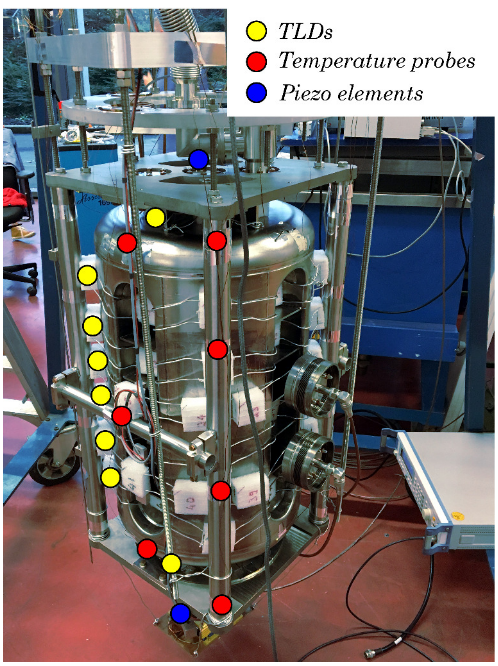

Figure 3: Cavity equipped with temperature probes, TLDs and piezo elements in preparation for the assembly into the vertical cryostat.

MEASUREMENT RESULTS

After cooling down the cavity to 4.2 K initial rf conditioning of low multipacting barriers < 3 MV/m has been performed for three days. Further barriers in the range between 3 MV/m and 6 MV/m could permanently be surmounted. Barriers occuring above 6 MV/m could also be surmounted but still remained softly within different measuring procedures. Assuming an improved surface preparation it should be possible to cross these recurring barriers persistently as well. In a next step the performance of the cavity has been tested. During the whole testing phase the residual pressure inside the cavity was in the range of 10^{-8} mbar. Figure 4 shows the corresponding Q_0 vs. E_a curves before (red curve) and after (blue curve) rf conditioning. At low fields a very high Q_0 of $1.44 \cdot 10^9$ could be achieved. Since High Pressure Rinsing (HPR) could have been performed only along the beam axis because of technical restrictions by the manufacturer, the performance of the cavity is limited by field emission at even low fields. A new HPR installation which is currently under construction will allow to rinse each quadrant of the cavity in future. Thereby the performance should be increased significantly. Nevertheless, the design quality factor at 5.5 MV/m could be exceeded by a factor of 2. A maximum gradient of 7 MV/m corresponding to 4.2 MV voltage (4 W stored energy) was reached. The related peak electric and peak magnetic field was 44 MV/m and 39 mT, respectively. At that gradient Q_0 dropped down to $1.98 \cdot 10^8$ which equals the external Q_e factor of the input coupler. Higher gradients were limited by field emission at that time.

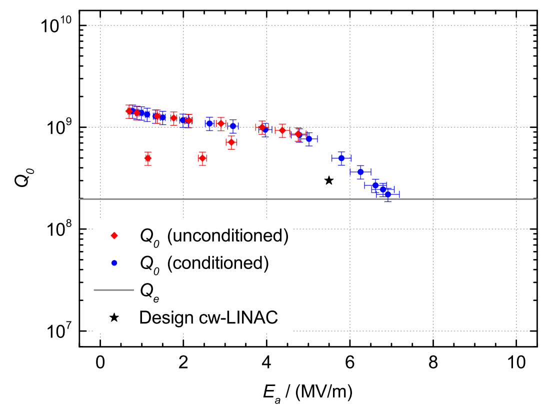

Figure 4: Measurement of Q_0 vs. E_a at 4.2 K before (red curve) and after (blue curve) rf conditioning.

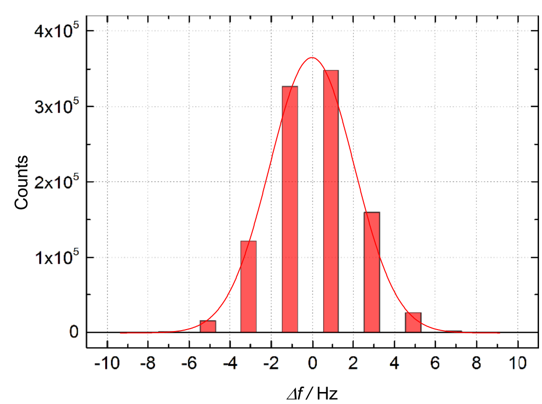

Figure 5: Long term VCO measurement.

Furthermore, the VCO (voltage controlled oscillator) signal coming from the rf control system has been recorded with a scope over several hours at 2 MV/m to perform long term statistics concerning stable operation of the cavity (see

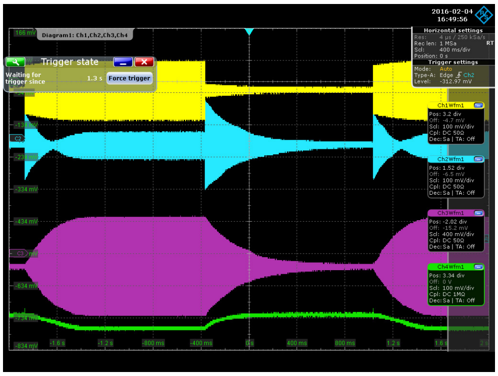

Figure 6: VCO response signal (green curve) due to Lorentz-Force-Detuning at a field level of 5.3 MV/m.

Fig. 5). Thus dynamic frequency variations caused by vacuum pumps or by fluctuations in the liquid helium bath could be analyzed for example. The long term measurement shows a very stable operation of the cavity with a maximum frequency shift of ±7 Hz which was compensated by the control system. In addition to that, measurements in pulsed operation have been performed to investigate the Lorentz-Force-Detuning (LFD) behaviour of the cavity. Figure 6 shows the VCO response (green curve) at a field level of 5.3 MV/m. A maximum frequency shift of about −80 Hz was compensated by the control system which yields to a LFD factor of $K = -2.1\,\mathrm{Hz}/(\mathrm{MV/m})^2$ (see Fig. 7).

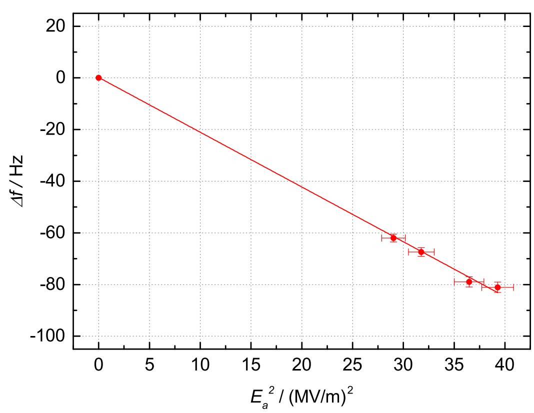

Figure 7: Measured frequency shift caused by LFD.

To analyze the effects of mechanical resonances on the cavity's frequency at 4.2 K especially regarding microphonics, the modes of the cavity have been determined. For this purpose, a piezo actuator driven by a harmonic ac voltage was used to stimulate the cavity while the mechanical amplitudes have been recorded with a second piezo element acting as a sensor. In Figure 8 the mechanical spectrum of the cavity (red curve) as well as the corresponding VCO response (blue curve) is shown depending on the excitation signal. As one can see from the VCO signal, mechanical resonances particularly at 143 Hz, 180 Hz and 318 Hz influence the fields inside the cavity and cause frequency shifts in order that the rf control system has to intervene. Other modes for example at 493 Hz have no effect on the resonance frequency. The peak at 50 Hz is an artefact coming from poor cable shielding.

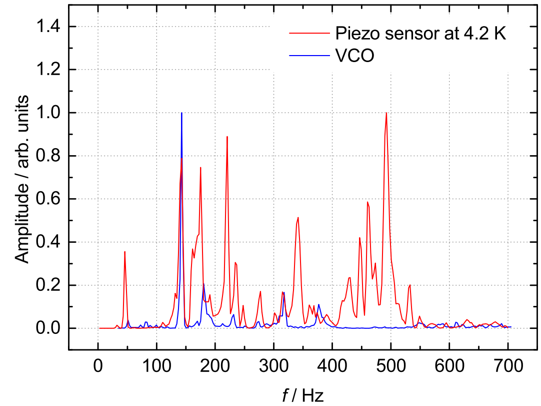

Figure 8: Mechanical modes and corresponding VCO signal due to the excitation signal at 4.2 K.

SUMMARY & OUTLOOK

The sc 217 MHz CH cavity has been successfully tested with low level rf power at 4.2 K. A very promising gradient of 7 MV/m could be reached. Due to insufficient surface preparation because of technical issues the cavity is limited by field emission at even low fields. An optimized HPR installation, which is under construction at the moment, will allow to rinse each part of the cavity. This should lead to a significant increase of the cavity's performance in future. Nevertheless, in a next step the cavity together with two sc solenoids will be mounted into the new horizontal cryomodule at GSI. A first full performance test of the cavity with beam, which will be provided from the GSI High Charge State Injector, is planned in the 4th quarter of 2016.

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