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SURFACE PREPARATION AND OPTIMAZITION OF SC CH CAVITIES

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Abstract

The Institute of Applied Physics (IAP) introduced the superconducting multi-gap CH-structure, which is mainly designed for low beta hadron acceleration. In 2017, a 217 MHz sc CH-structure was successfully tested with beam at GSI and multiple CH-structures are currently under development for the GSI cw linac. RF performance of all sc cavities are limited by the surface properties of the used material. Therefore, sufficient surface preparation and optimization is necessary to achieve optimal performance. Presently as standard procedure BCP and HPR is used for CH-cavities. Several surface treatments will be applied to the very first CH-prototype, a 360 MHz, 19-cell cavity. Prior to the first treatment, the status of the cavity was examined, including leak tests and performance tests at 4 and 2 K. This paper presents the performance development of a sc CH cavity depending on different preparation methods.

INTRODUCTION

Many application and experiments demand ion beams of high repetition rate or cw operation. The gradient of normal conducting cavities are limited by their cooling system in such cases, making conservative choices necessary when avoidance of beam down times are of vital importance [1]. Superconducting RF cavities do not have such cooling problems at CW operation, making them more desirable for experiments with high repetition rates. Difficulties with SC RF cavities stem from different mechanism, which can limit performance and are topic of this paper. The increase of performance and efficiency is obviously of high interest, leading to higher achievable gradients and fewer cryogenic losses, effectively reducing the operational cost of the accelerator. Several procedures are currently under investigation and developed to further optimize surface properties of niobium cavities and samples. The institute for applied physics (IAP) currently finalizes CH1 and CH2 of the CW-LINAC for GSI. The RF design phase of the remaining CW Linac CH structures is currently ongoing, with first designs for CH3-11 beeing presented at SRF 2019 [2]. Optimization of CH structure performance is a direct performance improvement of the CW-LINAC, which saves operational costs and could possibly expand the variety of applications. For this reason a 360 MHz 19 gap CH prototype will be used to (test) preparation methods beyond BCP, HPR and RF conditioning, which are currently the standard for CH structures. Further preparation methods such as EP, nitrogen doping/infusion, HPP, helium processing and more have been and are mainly performed on elliptical cavities and samples. Some preparation methods are currently not well understood yet and have to be carefully selected. Different mechanism take place in the Q-E slope, depending on field levels in the cavity which can be distinguished into three areas: low, medium and high field Q-slope.

PERFORMANCE INCREASE OF SC CAVITIES

Low Field Q-slope

For very low field levels, the Q-E curve shows an initial rise to the maximum of the curve at 15 mT to 20 mT, which presumably represents the traditional BCS value. Experiments have shown, that the low field Q-slope is more pronounced when residual resistance is low and baking increases the Q-slope [3]. HF rinsing of cavities after baking restores the Q-slope to the state before baking. Rebaking then restored the stronger low field Q-slope. This suggests that the metal-oxide layer is responsible for this effect, which worsens the superconductivity. According to one model, suboxide clusters introduce localized quasiparticle states in the gap region, effectively reducing the gap [4].

Medium Field Q-slope

The medium field Q-slope, up to 100 mT, decreases the Q value by a factor of roughly 2-5. This increases cryogenic losses for medium and high field cw applications and therefore increase the operational costs. The easiest model is the thermal feedback model. It states that higher field levels lead to higher RF losses and heating, increasing the BCS resistance. This triggers a loop effect, since higher BCS resistance will result in higher RF losses at equal field levels. This model works well for high frequency models, for low frequencies below 1 GHz cavities show less of such global instabilities, due to the quadratic frequency dependency of the BCS resistance. Important parameters for the medium field Q-slope are given by bath temperature, frequency and phonon mean free path length. Nitrogen doping and infusion are treatment options with potential, which currently produce mixed results and overall is not well understood yet. Nitrogen doping and infusion are baking processes that are performed with a constant nitrogen flow through the cavity at a given pressure. Recipes vary from laboratory to laboratory, in general the baking temperature lies between 100 °C and 800 °C with baking times of minutes to hours [5, 6].

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High Field Q-slope

Beyond 100 mT a rapid decrease of the intrinsic quality factor occurs, even in absence of field emission. The mechanism behind this is magnetic heating. Micron sized defects at the niobium surface become highly resistent above an onset field strength. This additional heating further increases temperature and BCS resistance, amplifying the thermal feedback loop. Mild bakes at 120 °C for 48 h are the standard procedure to reduce the high field Q-slope. These benefits are preserved even after water and air exposure, showing that the metal oxide layer does not contribute to the high field case.

Field Emission

Field emission represents a "hard" limit for cavity performance. Bulk impurities at the surface emmit a tunnel current. The current depends on peak field level at the impurity, which is amplified by it's geometry [3]. The current grows exponentionally with field level and demands increasing share of forward power. This directly translates into localized heating, where the beam collides with the resonator, leading to quench of the cavity at an onset field level. It is also not well understood when an impurity becomes an emitter. Experiments have shown that processing of active emitters can lead to the activation of previously inactive impurities. High Power Processing (HPP) has shown the decrease of field emission. Very short high power pulses produce high peak fields at the emitter and produces a plasma, which then collides with the emitter and destroys it. Succesful processing of emitter shows in form of a crater called "starburst" at previous emitter location. The crater has no negative effect on cavity performance [3]. Helium processing performs analog to HPP but under added helium in the cavity. This reduces the required power of the pulse.

CH PROTOTYPE

Treatments will be performed on a 360 MHz 19 gap CH prototype. The cavity was stored under a slight nitrogen overpressure for over 10 years, model shown in Figure 1. First power tests will have to show if store times of such

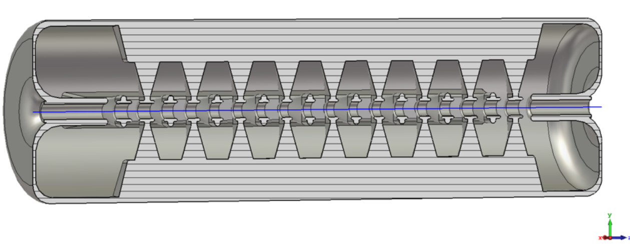

Figure 1: CST model of the CH prototype.

lengths compromise the performance of the cavity, experimental setup is shown in Figure 2. As first measurements low field measurements were performed to check the current state of the cavity. Vacuum was produced by the combined use of a three stage membran prepump followed by a turbo

Figure 2: Experimental setup for vacuum and low RF measurements.

pump and the finally a getter pump. A vacuum of E-10 was upheld for a couple of weeks without any incident. RF measurements with a network analyzer and amplifier have shown a resonance frequency of 360.251 MHz. CW operation with a frequency generator, amplifier and regulation system have shown resonance at 360.2498 MHz. Pulsed operation with 9 ms pulse length has shown strong coupling. The coupling strength in pulsed operation results from the two peaks of the reflection pulse. The first peak shows the forward power and the second peak shows the coupler power.

$$\beta_L = \frac{1}{2\sqrt{\frac{P_{on}}{P_{off}}} - 1} = \frac{1}{2\frac{U_{on}}{U_{off}} - 1} \tag{1}$$

The pulsed reflection signals showed a rough ratio of 1:2 which results in an infinite coupling strength. The error of β_L increases with increasing β_L. An estimate for the error of β_L is given by equation 2.

$$\Delta\beta_L = -\frac{\Delta U_{on}}{U_{off}\left(2\frac{U_{on}}{U_{off}} - 1\right)^2} + \frac{U_{on}\Delta U_{off}}{U_{off}^2\left(2\frac{U_{on}}{U_{off}} - 1\right)^2} \tag{2}$$

One peak could only be measured with an error of $\Delta P = 0.2$ mV. The bandwidth of forward and reflected signal were measured, resulting in an error of $\Delta P = 0.4$ mV. All pulsed peak measurements resulted in ratios slightly above 1:2 and delivered negative β_L values, listed in table 1 The pulsed signal measurements did not deliver useful results in term of coupling strength, but it constantly delivered consistent

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Table 1: Pulsed β_L Measurements

Pon	Poff	β_L
49.031 mV	98.36 mV	-330
78.092 mV	157.974 mV	-88
93.294 mV	189.27 mV	-70
38.301 mV	76.9 mV	-86
115.052 mV	231.892 mV	-130

values for τ_L of 9.4 ms. The quality factor Q_L was calculated with equation 3.

$$Q_L = 2\pi f \tau_L \tag{3}$$

A value of $2.13 \cdot 10^7$ for Q_L is obtained. As the final measurement β_L was calculate of cw operation at different power levels.

$$\beta_L = \frac{1 + \sqrt{\frac{P_r}{P_f}}}{1 - \sqrt{\frac{P_r}{P_f}}} \tag{4}$$

Equation 4 holds true in case of strong coupling. The results are listed in table 2. Last previous measurements were performed in 2007 and had shown $Q_L = 1.23 \cdot 10^8$, $\beta_L = 4.54$ and $Q_0 = 6.8 \cdot 10^8$. The comparison with those values shows, that the cw β_L values of 38-50 are slightly higher than the estimation predicts. The best case scenario is a Q_0 that has not decreased and the coupler quality remained equal. This would suggest a coupling strength of 32 and is close to observed values with respect to the margin of error. The higher β_L values could stem from an unlikely deterioration of the coupler or due the small count of measurements.

Table 2: CW β_L Measurements

Pr	Pf	β_L
0.1081 W	0.1188 W	42
0.916 W	0.988 W	48
1.453 W	1.614 W	38

CONCLUSION

The coupler will be examined in the clean room at IAP Frankfurt after SRF'19. It is expected that coupler position has changed, because the coupler quality factor depends on it's geometry and field level of the induced cavity mode and deterioration is not expected. A RF test will follow afterwards, taking the Q-E curve at 4 K and check for the remaining performance of the cavity.

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