A COLD BEAD-PULL TEST STAND FOR SRF CAVITIES

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Abstract

Bead-pull measurements represent a final step in the fabrication process of an SRF cavity. These tests allow to characterise the flatness of the field profile in order to mechanically tune the cavity to achieve design specifications. The realization of a bead-pull measurement is always performed at room temperature and therefore it is influenced by the material physical properties resulting into higher surface losses as compared to the superconducting state. Moreover, questions like mechanical deformation due to asymmetrical thermal shrinkage through the cool-down process and the stress created by the tuner actuation have not yet been answered experimentally. In this paper, an upgrade of the former Cold-Bead pull system developed by HZB [1] is presented. This test-stand is capable of holding a 9-cell Tesla cavity at LHe temperature providing a realistic insight to cavity parameters under operation conditions. In addition, a copper test pill-box is placed in series with the multi-cell cavity in order to perform 1.8K calibration of the bead. Test results of the commissioned test-stand prototype are presented on this paper.

INTRODUCTION

Many different mechanical systems have been developed and used by industry and Labs as a working tool to accurately perform final tuning of the cavity geometry in order to fulfil specifications [2,3]. As it is known this process is always performed under “warm conditions” with the focus on the operating fundamental mode as a quality indicator. HZB approach is to develop a test-stand capable of analysing the field profile characteristics of a Niobium prototype in a SC regime. The goal is to be able to validate the future fabricated prototypes while having a deeper insight on the cavity changing response due to environmental conditions such as temperature through the cool-down process. As it is detailed in [1] the cold bead-pull test-stand offers the possibility to analyse and characterize the field profile for the fundamental TM_{010} band within a 1.8K environment as well as high order modes (HOMs). The later measurement becomes often very complicated since it is masked by the high surface resistivity of Niobium above 9.2K. As it is later discussed the presented test-stand is an slight modifications of the former prototype where limitations such as field saturation for the fundamental TM_{010} band due to the size and metallic condition of the bead are solved. The set-up has been commissioned in HoBiCaT [4] by the characterizations of a 1.3GHz 9-cell Tesla cavity with mounted Helium vessel and tuner. As a result accurate field profiles and R/Q values have been obtained. A 1.3GHz Copper pill-box has been placed in series with the measured 9-cell Tesla in order to perform the necessary bead calibration and measure the corrected form factor of the bead under experiment environmental conditions which would allow the correct determination of the R/Q values.

BEAD-PULL TESTS-STAND

Main mechanical modifications required consist on the enlargement of the supporting aluminium structure to hold the two cavities within the HoBiCaT [4] space capabilities (Fig.1). As it is later described the size and material of the bead has also been changed to modify the system´s sensitivity.

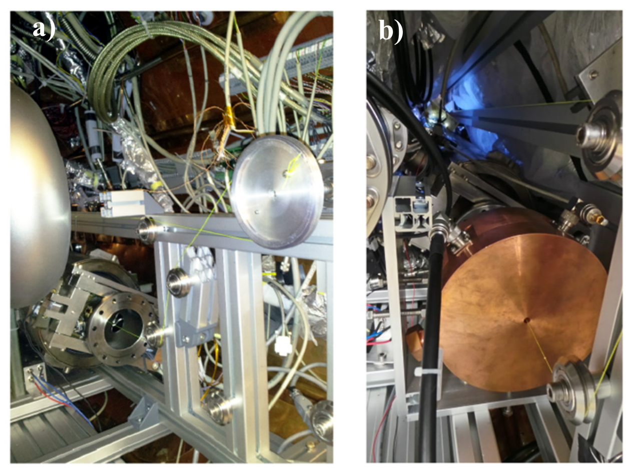

Figure 1: 9-cell Tesla cavity mounted on the test-stand before the installation of the pillbox (a). Pill-box cavity mounted with the wire system inside the HobiCat cryo-module (Niobium 9-cell cavity hidden behind) (b).

The commissioning procedure is performed in two phases. On the first stage the bead is placed at the beginning of the run (pill-box side) and several runs are performed to derive the experimental form factor *(f_{bead})* of the bead by comparing with the simulated eigenmode response (COMSOL Multiphysics [5]). On a second stage and once the form factor is known, the bead is allowed to enter the cavity under analysis to perform the analysis of the selected bands of interest.

Bead Calibration

Due to the high sensitivity of the field response to the used metallic bead under LHe temperature found in the 1st experiment [1] a smaller dielectric bead was chosen (spherical Macor ε_r=6, r=0.75mm, r_{hole}=0.25mm) in order to avoid saturation on the fundamental pass band. As it was already described, a copper pill-box (l=75mm, r=174.2mm, r_{hole} =3.5mm, wall thickness=10mm) was measured as a control cavity for calibration purposes. In order to obtain the maximum accuracy on the bead form factor (f_{bead}), the effect produced by the bead hole as well as pill box openings on the longitudinal field component and its frequency and phase shift has been considered. The analytical calculated form factor is given by Eq.1 (f_{calc}=7.33e-21). By comparing both simulation results and measurements a first scale factor, s=.716 is extracted from Eq.2 (Fig.2a). Nevertheless a second scale factor s^* must be consider to account for the extra phase displacement of +0.012° induced by the presence of the bead hole (Eq.3). As a consequence the final corrected form factor is found to be f_{bead}=5.083e-21

$$f = \pi r^3 \varepsilon_0 \frac{(\varepsilon_r - 1)}{(\varepsilon_r + 1)} \qquad (1)$$

$$s = \frac{R/Q_{meas}}{R/Q_{sim}} \qquad (2)$$

$$f_c = f \cdot s \cdot s^* \qquad (3)$$

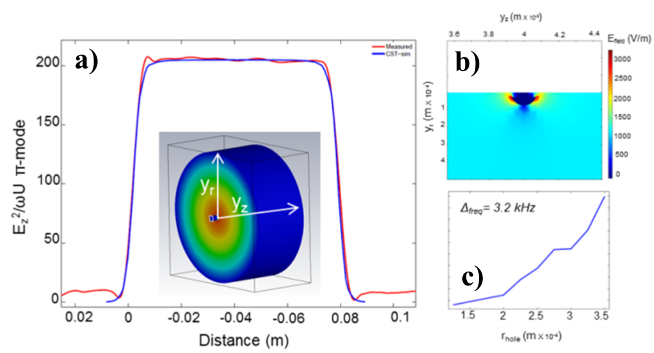

Figure 2: Comparison field profile extracted from EM simulations and pill-box measurements (a). Field profile simulation for a hollowed bead (b). Frequency shift induced for different bead holes radii (c).

1.3GHz 9-cell Tesla Cold-tests

Along the testing phase of the Niobium prototype the different field profiles as well as R/Q values are extracted for several frequency bands. For comparison purposes, the values given in R.Wanzenberg´s note on the 9-cell Tesla cavity are taken as a reference [6]. In a first step the fundamental TM_{010} band is evaluated. Due to the use of a smaller dielectric bead no saturation effects are found. As detailed in [1] phase shift method is used due to the characteristic sensitivity. Phase deviations for the whole band (TM_{010} 1/9 π – π) are measured in the range from (3°-15°). Figure 3 depicts the measurement result for the TM_{010} π, 3/9π and 6/9π modes. Extracted R/Q values for this modes are: *R/Q(π)*=1099, *R/Q(3/9π)*=0.032 and *R/Q(6/9π)*=0.12 with loaded quality factor of $Q_l(\pi)$=1e5, $Q_l(3/9\pi)$=1.95e5 and $Q_l(6/9\pi)$=6.9e4 respectively. A comparison between the TM_{010} π at 1.8K and room temperature is also depicted in Fig.3a. As it can be inferred, a slight field deviation is observed through the cool-down process resulting in a change of the field flatness of 1.25%.

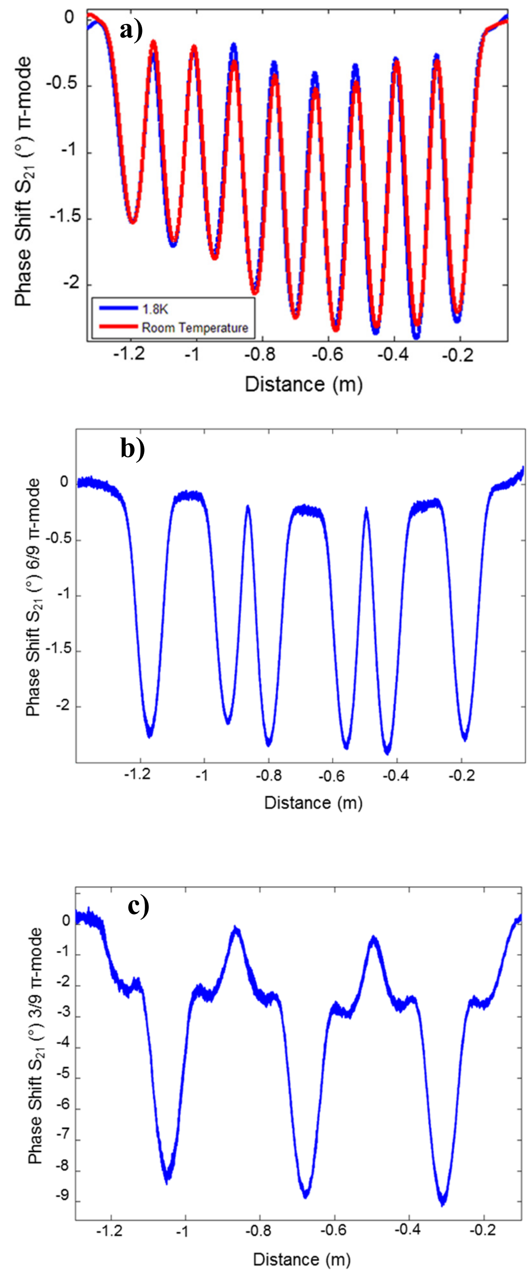

Figure 3: Measurement results on the fundamental TM_{010} pass-band phase deviation due to a dielectric (Macor r=0.75mm) bead. π-mode (a). 3/9π-mode (b). 6/9π-mode (c).

As it was previously introduced the cold operation of the 9-cell Tesla cavity allows the measurement of coupled modes from higher HOM bands to a level where their R/Q values can be calculated. Nevertheless and as expected HOMs become less sensitive to the selected dielectric bead showing smaller (<3°) phase shifts than in the case of a metallic sphere and cylinder of a bigger diameter. This was shown in [1] where an optimum field

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response was obtained and no saturation observed for the studied HOMs. Thus it is recommendable to consider changing the bead size or material when characterising these HOMs. Figure 4 depicts the measured $E_z^2/\omega U$ for the 8/9π-mode of the second monopole band (f(8/9π)=2.45GHz). The extracted R/Q(8/9π)=89 is proved to be in good agreement with Wanzenberg´s value (77.6) for the selected mode.

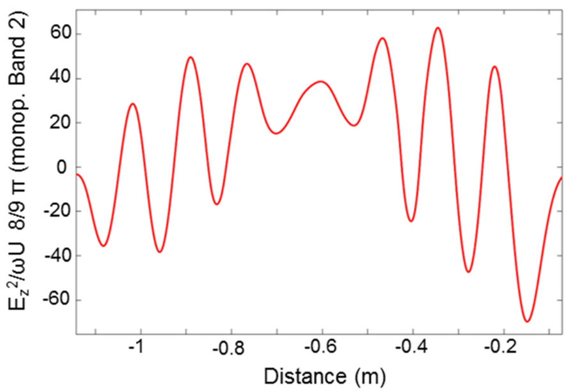

Figure 4: Measured HOM $E_z^2/\omega U$ profile for the 8/9π-mode in the second monopole band, f(8/9π)=2.45GHz.

In addition the effect of the stress produced by the actuation of the cavity tuner on the fundamental *π-mode* (1.3 GHz) was studied. Figure 5 show that a small tuning level of +-25kHz introduces an average deviation in the field flatness of 1.98%. Due to hardware limitations in the tuning range the measurement was not repeated for higher frequency offsets. Nevertheless a linear increase is expected and the consequences of applying realistic tuning ranges (+-250kHz) will be studied in future runs.

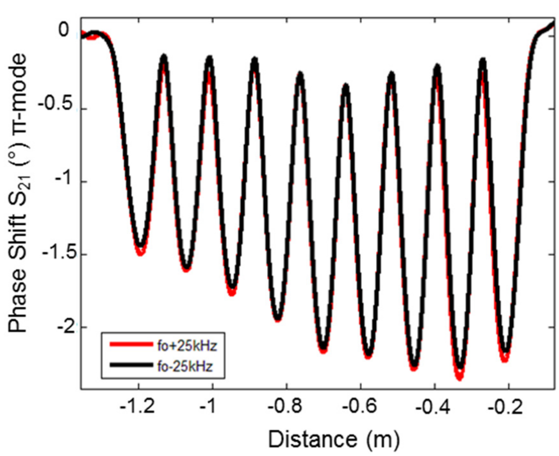

Figure 5: Measured phase shift induced by the tuner actuations on the TM_{010} *π-mode.*

CONCLUSIONS

As it is demonstrated in the present paper the cold bead-pull measurement set-up has been improved by the change of the bead type and size and the addition of a copper pill-box in order to solve the characterizations issues present in previous test [1]. As a consequence, the form factor of a given bead can be accurately determined under cold conditions and reliable results on the determination of the R/Q of the modes extracted. Moreover the set-up has proved the ability in accurately characterising the fundamental pass-band as well as HOM bands. In additions, the study shows interesting results in the analysis of the impact introduced by the tuner actuation with respect to the field profile. This effect is planned to be further studied in future tests. Therefore and to the light of the presented results the cold bead-pull test stand it is proved to be a great tool to have an insight on the effects produced by cool-down of the cavities to a superconducting state. Also the presented cold bead-pull test-stand represents a first step to the possible future development of a cold tuning machine.

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