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DEVELOPMENT OF A TE011 CAVITY FOR THIN-FILMS STUDY

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Abstract

Bulk niobium cavities have almost reached their maximum performances. Maximum accelerating gradient field is above 35-40 MV/m for a multi-cells cavity at 1.8 Kelvin and it achieves 25-30 MV/m with high reliability. The question of increasing the accelerating gradient in a significant way is running regarding the huge amount of units required for new projects (16000 units for ILC). A promising solution is to use thin films of new materials deposited on copper or niobium. In order to investigate the behaviour of these materials for the accelerating cavities, we have developed a dedicated setup based on thermometric method and a TE011 cavity. We present here the design study of the setup and the expected sensitivity of the method for the surface measurement of materials properties under RF fields.

INTRODUCTION

Superconducting thin-films, especially Nb on copper substrate, have been studied in the past for superconducting cavities at CERN [1,2,3,4]. These results highlight the performances of these materials: a high quality factor at low field, better than bulk, but a strong Q-slope when the accelerating field is increasing. Whereas these properties reveal that this technology was inappropriate for the high gradient cavities.

Recent studies on superconducting thin-films and other deposition processes and materials [5,6] have shown that a factor two on accelerating fields could be gained. The implications are significant: a decrease in the number of required cavities for the same final particle energy, a diminution of the size of the cryogenic facilities, a cost-safe on realisation and the exploitation of the machines, and an upgrade of the existing machines.

Regarding the impact of such technologies, we propose a dedicated TE011 cavity based on the thermometric method developed in the past within collaboration between CEA-Saclay and IPN-Orsay [7,8]. This method aims at characterize BCS and residual surface resistance of thin films samples.

We present here the design study of the cavity and the dedicated instrumentation. In a second part are presented the expected performances to conclude on the perspectives on thin-films characterization.

DESIGN OF THE TE011 CAVITY

Previous TE011 cavity setup [7,8] was used to characterize Nb and NbTiN coating on copper. The method has shown that it is possible to measure surface resistance (BCS and residual) with good sensitivity and precision. In order to study other thin films, we have designed a new cavity based on the same geometry.

TE011 Cavity

Calculations are performed with CST microwave Studio©. The cavity being designed to study BCS and residual resistance, the first step is to fixe the frequency. We aim at studying the possibility to apply thin- films for new cavity. For this reason, the frequency has to not be too high. However the size of the sample must be in the same order of magnitude than an accelerating cavity. Another requirement is to use 2 modes to perform measurement with two frequencies. By this way the surface resistance behaviour can be explored at two frequencies. Both modes TE011 and TE012 have a similar surface distribution on the sample. The magnetic field can be written with analytical expression depending on maximum magnetic field and Bessel function:

$$H_{S\max}^{TE012} = 2.H_{S\max}^{TE011}$$

$$H_S = \frac{H_{SMAX}}{J_1(kr_{\max})} J_1(kr)$$

Where J_1 is the first order Bessel function and $k=p_{11}/r_{cav}$ with p_{11} is the J_1's first zero.

This expression enables to use analytical formulae in the calculation of the surface resistance. The TE011 and TE012 magnetic field mappings are represented respectively on figures 1 and 2. These figures show that the maximum magnetic field is located at the bottom of the fedthrough, at the intersection with the top of the cavity.

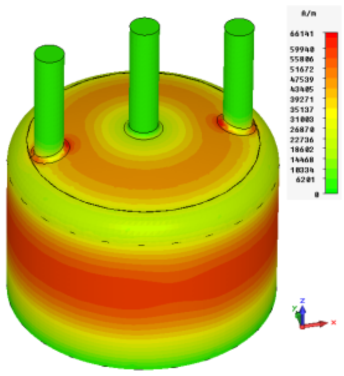

Figure 1.a: Tangential magnetic field on the cavity surface for the TE011 mode.

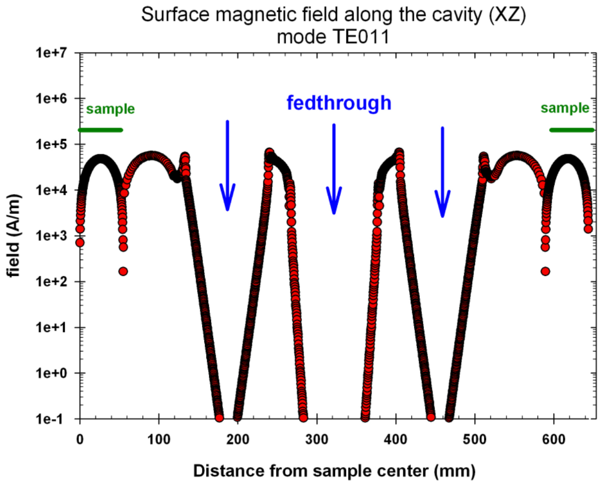

Figure 1.b: Surface magnetic field for the TE011 mode on the cut plane along the fedthroughs axis.

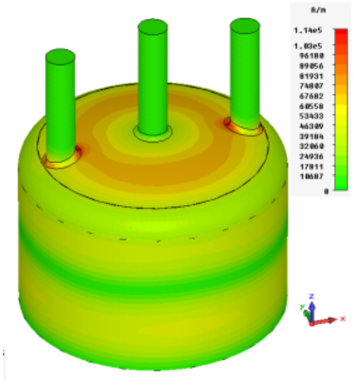

Figure 2.a: Tangential magnetic field on the cavity surface for the TE011 mode.

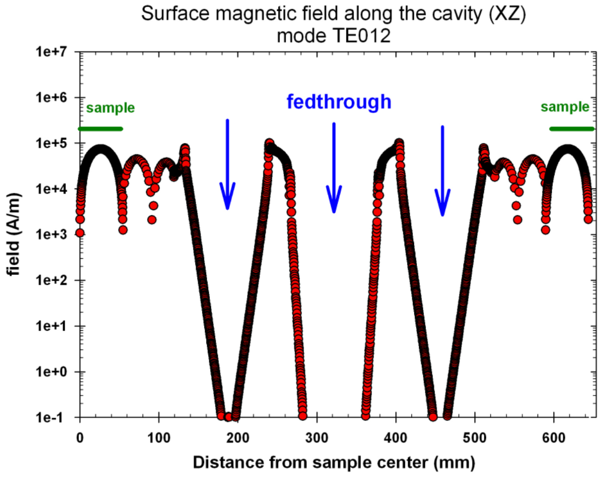

Figure 2.b: Surface magnetic field for the TE011 mode on the cut plane along the fedthroughs axis.

The round shape on the top of the cavity keeps away the degenerated modes and allows conserving the analytical expression of the magnetic field on sample surface, fixing the field ratio and modes frequencies. The Table 1 gives a comparison between the previous geometry and the new one.

Table 1: Comparison Between 1996 [7] Design and 2008 Design for TE011 and TE012 Modes

	1996 design	**2008 design**
Field ratio (TE011)	1.43	1.35
F_{TE011} (GHz)	4.02	3.85
F_{TM111} (GHz)	3.99	3.90
F_{TE012} (GHz)	5.62	5.12
F_{TM112} (GHz)	5.58	5.20
G_{TE011} (Ω)	722	773
G_{TE012} (Ω)	853	939

Measurement Chamber

The thermometers cell is shown on figure 3. The vacuum is required to perform high precision measurement. If the thermometers were directly inside the helium bath, the sensitivity of temperature measurement would be roughly decreased. 28 carbon thermometers are mounted on the backside of the sample and encapsulated in cooper piece to increase thermal conduction with the sample. The thermal contact is assumed by bronze-Beryllium made springs. 3 lines of 6 thermometers forming an angle of 120° between each other allow measuring the temperature profile from the centre to the border of the sample. 6 other couples of thermometers are mounted near the border of the disk. The temperature profile is correlated to the dissipated power on the sample. The vacuum of the chamber is insulated from the cavity. The cooling of the sample is made by the flange all around the 3 millimetres thick disk. This configuration allows dissipating few watts from the sample. The copper-made heater is fixed on the centre of the disk. It enables to calibrate both the thermometers and the dissipated power on the sample.

The method to measure surface resistance is described as follow [7]:

- At 1.8K, the main part of resistance is dominated by the residual regime. Once temperature variation has been measured on the backside of the sample by changing the power of the heater, we obtain the power dissipated in RF regime. The power dissipated is calculated by using the following equation :

$$P_s = \frac{1}{2}\oiint_S R_S(H_S,T)H_S^2(S)dS$$

- As we know the residual resistance, we can measure by the same method the BCS resistance from 1.8K to 4.2K by assuming the law $R_{BCS} = \frac{A}{T}e^{-\frac{B}{T}}$.

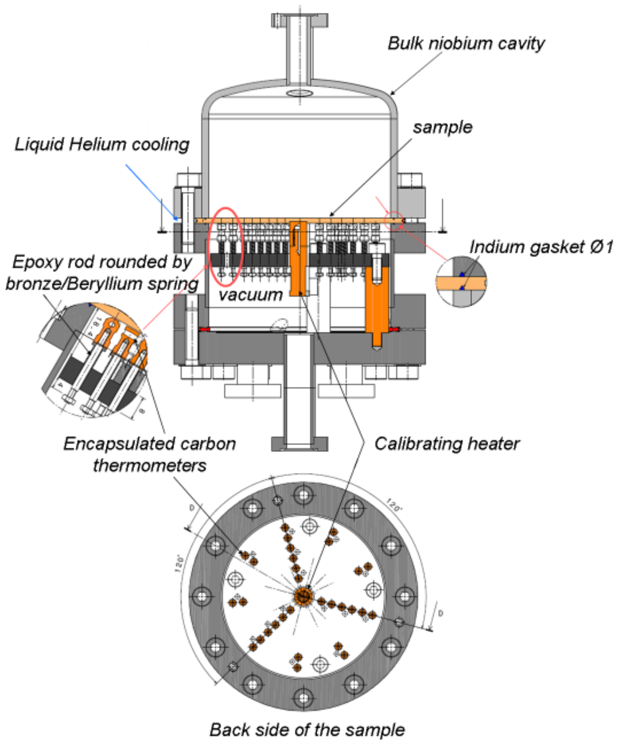

Figure 3: View of the TE011 cavity with the thermometers chamber.

EXPECTED PERFORMANCES AND STATUS

Expected Performances

This method has shown in the past that it is well adapted for measurements of thin films coated on copper substrate with a surface resistance similar to the niobium bulk. The expected performances are the same than previously. Following table summarizes the sensitivity:

Table 2: Expected Sensitivity for Different Magnetic Fields at 1.8K and 4.2K.

B_s(mT)	**Sensitivity (nΩ) @1.8K**	**B_s(mT)**	**Sensitivity (nΩ) @1.8K**
5	1.43	5	45
20	4.02	10	10
40	3.99	15	5

For a high quality sample, the quench of niobium cavity should limit the higher field applied. For the other cases, the measurements are limited by the thermal exchange conditions with the helium bath. Actually, the method requires measuring precisely the exchange coefficient. In this case, the transition between natural convection and nucleate boiling induces some difficulties. Otherwise, this phenomenon is not an issue and the measurements can be done out of the range of the transition. If these conditions are gathered, samples with a surface resistance from few hundred to few thousand nΩ could be characterized.

Status

This project has started one year ago. The cavity has been ordered and received (fig. 4), as well as the thermometers chamber and all instrumentation parts (fig. 5). Two niobium disks have been bought for the commissioning of the setup. First test with RF method must be done to validate the cavity.

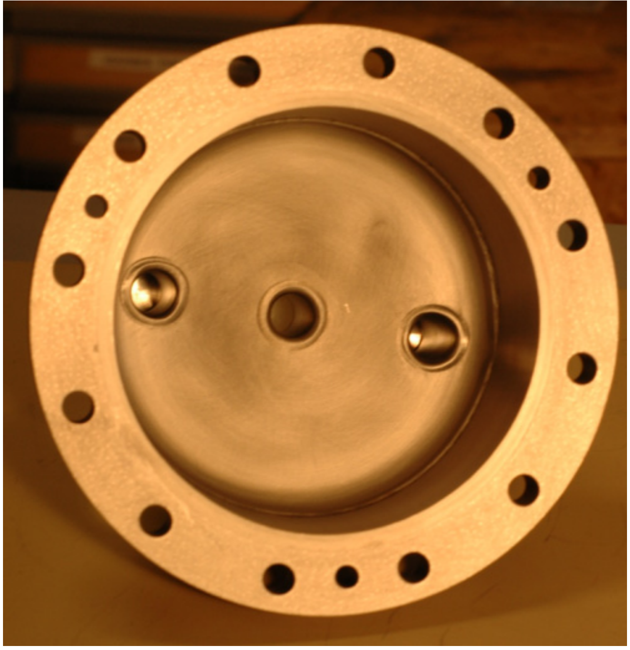

Figure 4: Bulk niobium cavity build by SDMS industry.

All parts must be assembled during next months in order to perform a complete test before the end of this year. The first step will be to perform the commissioning of the TE011 cavity by using a niobium sample. To achieve this objective, classical RF method will be used. The thermometric method will be tested after the first commissioning in order to compare the surface resistance measurements.

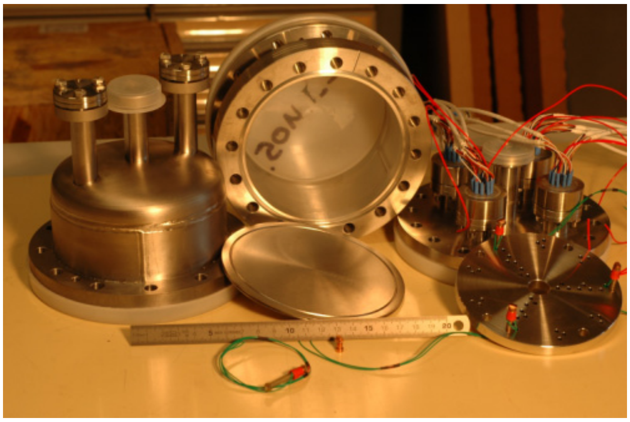

Figure 5: TE011 cavity, niobium sample and measurement chamber.

PROSPECTIVES

This setup will be dedicated to the surface resistance characterization under RF field. This allows investigating the grain boundary effect in niobium, the effect of impurity like hydrogen or oxides or other parameters for niobium bulk. In other way, it gives the opportunity to test new materials and/or news coating process. Some new materials like MgB2 [9,10,11], Nb3Sn [12,13] or A15 superconductors [14] could offer better performances. These new materials coupled with the theory of superconducting multilayer [5] could produce much better performances regarding the accelerating field and the cryogenic power.

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