SURFACE SCANNING THERMOMETERS FOR DIAGNOSING THE TESLA SRF CAVITIES

T. Junquera, A. Caruette, M. Fouaidy, IPN (CNRS - IN2P3) 91406 ORSAY cedex, France
Q.S. Shu, DESY, 2000 HAMBURG 52, Germany

ABSTRACT

In order to investigate the field emission and the thermal breakdown of 9-cell TESLA SRF cavities, 150 specially developed surface scanning thermometers have been built. The description of the thermometers and their calibration in superfluid helium are presented. A special test chamber equipped with a heated niobium plate is used to study the thermometer thermal response versus the heater power at different bath temperature. The comparison of thermometer response with numerical simulations results and experimental data obtained with reference thermometers mounted on the Nb plate using a thermal bonding agent, allows to get an estimation of the measurement efficiency of scanning thermometers. Experimental data obtained with cavities are analysed with the help of the calibration results and numerical simulations.

INTRODUCTION

The development of He II surface thermometers for diagnosing and studying the thermal effects in supercoducting RF cavities has been a major activity of the Orsay Group during the recent past years. Several papers describe the different types of thermometers and the main experimental features : fixed thermometers for studies of the anomalous heating of samples mounted on special cavities [1], scanning thermometers for monocell cavities [2] and special vacuum thermometers for Kapitza conductance measurements [3].

In this paper we present the first results of a new development in collaboration with the DESY laboratory, for constructing a diagnostic system for the 9-cell TESLA cavities. As compared to the older devices, a large number of thermometers (> 100) are mounted around the cavity which raises different mechanical and cabling problems. The complete description and the first results are given in an another paper at this conference [5]. In this paper we focuse on the calibration of the thermometers and the thermal analysis of the first temperature mapping results obtained.

DESCRIPTION

The surface thermometer design [Fig. 1] is very close to the model developed earlier for the CERN group [2]. The sensitive part is an Allen-Bradley carbon resistor (100 Ohm, 1/8 W) housed in a silver block with a sensor tip of 1 mm diameter for the thermal contact to the external surface of the cavity. This housing is thermally insulated against the surrounding He II by an epoxy envelope (Stycast) moulded around the silver block and into a bronze piece which allows the sensor mounting on the rotating thermometric arm. The thermometers tip must present a good contact with the cavity wall when scanning: two springs located inside two holes in the body of the rotating arm are used for this purpose, the contact pressure control and adjustement is allowed by means of two screws. Each thermometer has two independent manganin wires thermally anchored to the silver block with ~ 15 cm free length for connecting to each cell board (14 thermometers). At the level of the boards the connectors ensure the cabling dispatching inside the cryostat allowing the motion of the rotating arm.

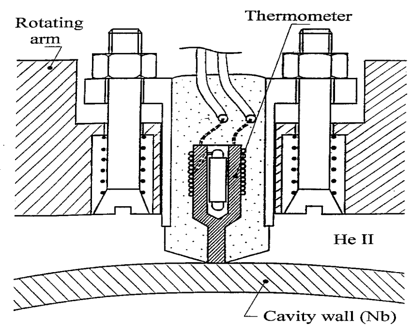

Fig. 1 : Cross section of a HeII surface thermometer

CALIBRATION

Superfluid helium

A representative batch (32) of the 150 thermometers fabricated for this device were tested using a special calibration chamber [1] allowing the mounting of 16 thermometers at every test. In principle all thermomters are located in a region subjected to the same heat flux density. In this experiment the thermometers tip were glued to the Nb heated plate by means of a good thermal bonding agent (Apiezon N Grease) in order to verify the fabrication process. The two thermometers batches (2 x 16) give a mean thermal response $<\Delta T>_1 = 8.0$ mK and $<\Delta T>_2 = 8.8$ mK respectively for a total heater power of 195 mW at T_{bath} = 1.8 K. Numerical simulation of the plate heater assembly for the same experimental conditions gives $\Delta T = 56$ mK. This calculation was performed in order to evaluate the thermometer efficiency η defined as the ratio of the experimental thermal response ΔT_{exp} to the simulated temperature jump ΔT_{sim} at the Nb - He II interface. In this case we obtained $\eta = 0.14$.

A complementary test was performed by mounting the thermometers in the real operating conditions of the scanning device, (e.g. without any bonding agent between the thermometer tip and the Nb wall). The results for a batch of 13 thermometers is presented in Fig. 2 at two different heater powers of 1.86 W and 2.8 W. A first group of thermometers was mounted with a contact pressure of ~ 10 bars (spring load of 80 gr) giving $<\Delta T>_{1.86}$ = 2.1 mK, a second group was monted with a pressure of ~ 62 bars (spring load of 500 gr) giving $<\Delta T>_{1.86}$ = 6.4 mK. A third group of fixed thermometers (e.g. glued with grease, not displayed) gives $<\Delta T>_{1.86}$ = 92 mK. At a higher power (2.8 W) the measurements were $<\Delta T>_{2.8}$ = 6.3 mK (at a pressure of 10 bars) and $<\Delta T>_{2.8}$ = 16 mK (at a pressure of 62 bars). All these results clearly show an important decrease of the measurement efficiency when no bonding agent is used : η is now close to 0.01. Notice that in this case, the efficiency is heater power dependant.

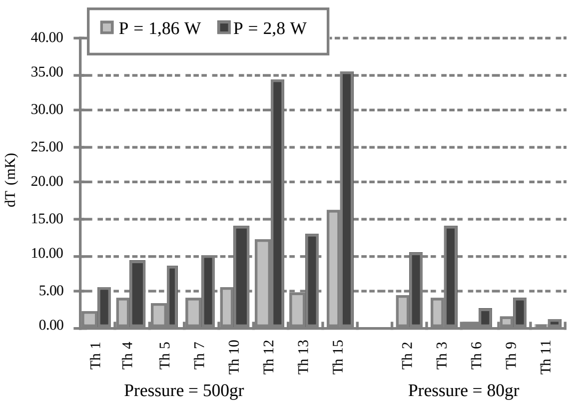

Fig. 2 : Thermal response at T_{bath} = 1.8 K (without contact grease)

Subcooled helium I

The subcooled helium bath obtained for temperature over the λ point (T>2.2K) and a pressure of 1 bar gives the possibility to study heat losses in the cavity wall in a far less constrained mode than in HeII. In this case the heat transfer mechanism is dominated by free convection cooling (laminar or turbulent) which induces the formation of a thick superheated helium boundary layer, the temperature is now quite easy to measure without taking many precautions in the mounting conditions of the thermometers. The calibration was made with the same thermometer batch and the same chamber. The results are displayed in Fig. 3. The same three groups of thermometers were tested giving respectively $<\Delta T>_{80g}$ = 572 mK, $<\Delta T>_{500g}$ = 651 mK and $<\Delta T>_{fixed}$ = 537 mK for a total power of 146 mW at 2.5 K. These values show clearly a rather insensitivity to the mounting conditions and a much reduced dispersion in each group as compared to superfluid helium results. The agreement with a previous published equivalent thermal resistance [4] in subcooled helium at 2.5 K is quite good : the mean measured value is R_{th} ~ 30 K/W/cm^2 which is consistent with the calculated value of 65 K/W/cm^2 for the same heater [4] power. This agreement seems to be quite good considering all the hypothesis and simplifications adopted to calculate this thermal resistance in a free convection bath with turbulent flow using dimensional analysis. Anyway and as expected, the comparison with superfluid helium results in terms of thermal boundary resistance (e.g. R_{th} ~ 2K/W/cm^2, Kapitza resistance at 1.8K) shows up the benefit of operating in subcooled normal helium. However, the price to be paid is a reduced spatial resolution and a reduced operating accelereting field due to the global cavity heating.

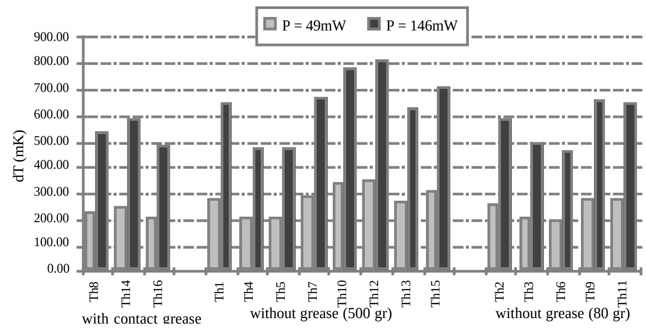

Fig. 3 : Subcooled normal helium test 2.5 K < T_{bath} < 3 K

EXPERIMENTAL RESULTS

The first experimental results using a completely equipped rotating arm (116 thermometers) have been obtained with a prototype TESLA cavity (1.3 GHz, 9 cells) [5]. This cavity, after a heat treatment at 1400 °C in a vacuum furnace, was tested in a vertical cryostat at the DESY TTF facility. During the experiment, high power processing (HPP) was performed which leads to an important improvement of the cavity performances : E_{acc} = 20 MV/m at Q_0 = 2 x 10^9 (Q_0 at low field ≥ 10^{10}). Several T-maps were recorded during the test in superfluid helium bath (before and after HPP) and in a subcooled helium bath (after HPP).

a) Superfluid He II bath

During the first run, the cavity reach a maximum accelerating field (E_{acc}) of 11.2 MV/m limited by a very heavy field emission. The Q_0 decreased from ≥ 10^{10} at low field to 8 x 10^8 at the maximum field. A first T-map was recorded at this value exhibiting very high ΔT in the 5th cell. The heated region was very extended : it concerns 12 thermometers of the 5th cell (Fig. 4) and presents several maximums at different angles between 100 ° and 200 ° (Fig. 5). Very high ΔT were measured (1K - 3.3 K) in this cell.

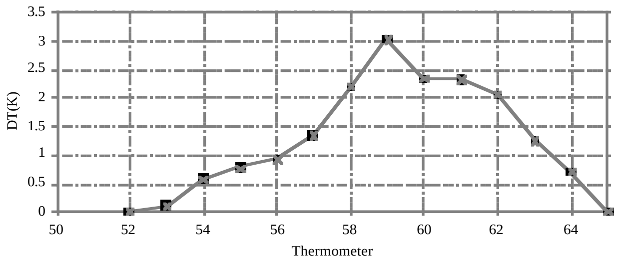

Fig. 4 : ΔT (5th cell thermometers) at 130° azimuthal angle

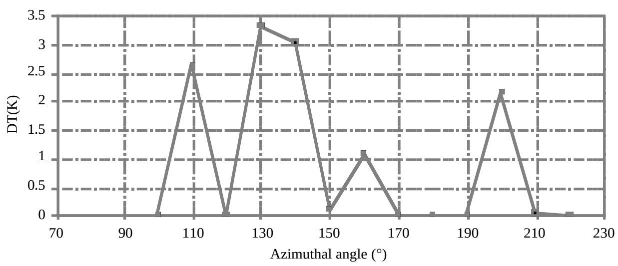

Fig.5 : ΔT (thermometer #59) vs. azimuthal angle

The first question raised by these results is if we may trust the measurements. In order to explain that a very high measurement efficiency of the thermometers must be considered. During the thermometer calibration the measurement efficiency has exhibited a strong dependance on the heat power level : the efficiency is multiplied by 2 when the power is increased from 1 to 3 W. This is completely different from the behaviour of fixed thermometer using a thermal bonding agent (Apiezon grease) which exhibits a ΔT linearly proportional to the heater power. Evidence of high ΔT measured in monocell cavities with scanning thermometers has been observed many times. Values of ΔT in the range of 100 mK to 200 mK have been measured in Nb/copper cavities at CERN [2] with largely lower RF power levels (~ 2 to 10 W).

If we admit a very good efficiency at the high heat flux density encountered in this cavity, another questionable point remains : are such high heat flux density levels compatible with the critical heat flux in He II ? Some references on this subject confirms that metallic heated plates in He II exhibit very high ΔT (5 to 6 K) in the Kapitza regime before reaching the critical flux inducing the transition to film boiling [6].

Extensive calculations of electrons trajectories at 11.2 MV/m shows that emission sites located in the proximity of the iris of the 5th cell could explain such impacts in the equator region of this cell. The azimuthal spreading of the heated area is more difficult to understand. Model calculations simulating a unique emitter site provocating a rather thin electron impact along the azimuthal can explain a smaller angular spreading in the cold face of the cavity. To explain the ΔT shapes observed, a first hypothesis of separated sites located in the same cell at different angles along the iris must be admited. From the point of view of the total power involved in this experiment we have performed the integration of the heat power density over the heated region :

$$Q = \int_s q ds \approx S_{th} \sum_n h_k \Delta T_n$$

where S_{th} is an estimation of the equivalent heated surface measured by one thermometer which has been arbitrarily taken equal to the product of the distance between two thermometers and length corresponding to a scanning angle of 10°. h_K is the Kapitza conductance at the measured point

$$h_k = H_K.f(\Delta T) = h_o\, T_{bath}^n \,.\, f(\Delta T/T_{bath})$$

$$H_k = 0.017\ T^{3.62}\ W/cm^2K$$ [7].

This integration gives Q ~ 100 W which seems to agree quite well with the RF power measurements. The power attributed to the electrons is easily deducted from the ΔQ_O at E_{acc} = 11.2 MV/m ($\Delta Q_O = 10^{10} - 8 \times 10^8$). A simple calculation gives $P_{electron}$ ~ 170 W. So, we obtain values which are of the same order of magnitude : the discrepency could be attributed to HK variations from Nb sample to another and to η which is not exactly 1. This good agreement could add some confidence to the recorded ΔT.This strong field emission was efficiently treated by HPP technique in the same experiment and a very good Eacc value was reached (20 V/m). A T-map taken at 17.7 MV/m shows that the heating observed in the 5th cell has disappeared and that some lower heating is now measured in the cells #5 and #7 reaching some peaks of ΔT ~50mK at angles of 100° and 280°.

b) Subcooled helium bath

Several T-maps were performed in a subcooled HeI bath at bath temperature in the range 2.3 - 2.5K with E_{acc} ~18 MV/m. All the maps shows a global heating (ΔT) ~ 400 mK of all the cells and some scattered hot points in cells # 5 and # 7. It is interesting to compare this measured values with the results obtained during the calibration : the surface resistance ($R_{BCS} + R_{residual}$) at a wall temperature of 3 K is estimated to be R_S = 150 nΩ. In the equator region of the cells the surface magnetic field corresponding to Eacc = 18 MV/m can be computed : Hs ≅ 6.10^4 A/m. Then the heat flux density in this area is calculated : $q_S = \frac{1}{2} R_S H_S^2 \approx 27 mW/cm^2$. Considering the equivalent thermal resistance measured during the calibration tests in subcooled helium (R_{th} ~ 30 K/W/cm^2) we can estimate the resulting heating : ΔT ~ 800 mK. This is a good agreement with the measured values when we take into account all the simplifications adopted to perform this estimation the thermal resistance depends on the heated surface orientation with respect to the vertical (buoyancy force).

REFERENCES

[1] M. Fouaidy, T. Junquera, A. Caruette, Proc. 5th Workshop on RF Superconductivity Hamburg (1991) p. 547,

[2] Ph. Bernard, D. Bloess, E. Chiaveri, C. Hauviller, T. Schiller, M. Tauffer, W. Weingarten, P. Bosland, A. Caruette, M. Fouaidy; T. Junquera, Proc. 6th Workshop on RF Superconductivity (Newport News, Oct. 1993) CEBAF report, p. 739,

[3] S. Bühler, A. Caruette, M. Fouaidy, T. Junquera, Proc. 6th Workshop on RF Superconductivity (Newport News, Oct. 1993) CEBAF report, p. 1002,

[4] R. Romijn, W. Weingarten, IEEE Trans. on Magnetics, Mag 19 (1983), p. 1318,

[5] Q.S. Shu, G. Deppe, W. Moller, M. Pekeler, D. Proch, D. Renken, P. Stein, C. Stolzenburg, T. Junquera, M. Fouaidy, A. Caruette, (this conference),

[6] A.Kashani, SW. Van Sciver, Cryogenics 25 (1985) p.238

[7] K. Mittag, Cryogenics 13 (1973), p. 94.