High Field Q-slope's Studies Using Thermometry

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Abstract

Thermometry[1] shows the distribution of the power dissipation on the cavity surface. Together with quality factor it characterizes cavity performance. In this paper we present thermometry results to improve understanding of the high field Q-slope.

EXPERIMENTS

The experiments were carried out with chemically treated cavity, LE1-30. Before each test the cavity was rinsed for two hours in the clean room with high purity water under 1000 psi high pressure. Cavity assembling and disassembling was done in the clean room class 100. The sequence was following:

- The cavity was polished for 20 min with BCP(1:1:2). The temperature of solution was below 15°C.
- The cavity was tested at the bath temperature of 1.5°K.
- The cavity was baked at 100°C for 48 hours under UHV conditions.
- The cavity was tested at the bath temperature of 1.7°K.

The results before and after baking for chemically polished cavity are presented in Fig.1 (in all figures quality factor is plotted versus peak surface magnetic field). The low field quality factor was around $2 \cdot 10^{10}$ at bath temperature 1.5-1.7 K. The highest peak surface magnetic field which we reached in our baseline test was around 110 mT

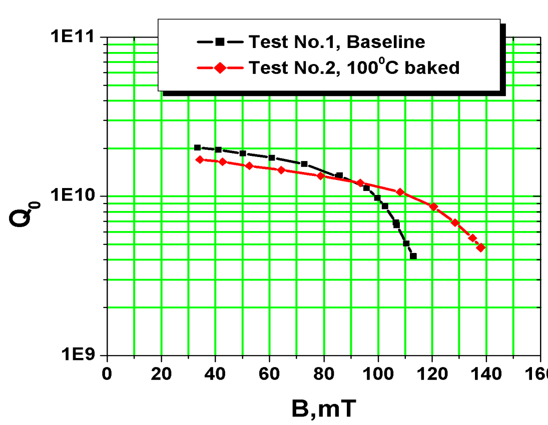

Figure 1: The test results of chemically polished cavity. The typical error in experiments is 10% in quality factor and 5% in field measurements.

with quality factor around $5 \cdot 10^9$. The temperature map shows that both on the top and on the bottom half-cells there were "hot" and "cold" regions (Fig.2.). X-rays were not detected in this test.

The baking treatment shifted the onset of the high field Q-slope to higher fields. After 100°C baking we get to 140 mT with quality factor of $5 \cdot 10^9$. It is possible to distinguish between "hot" and "cold" regions on the cavity surface, but this time the hot test regions were present mostly on the top half-cell (Fig.3.). X-rays were not detected in this test.

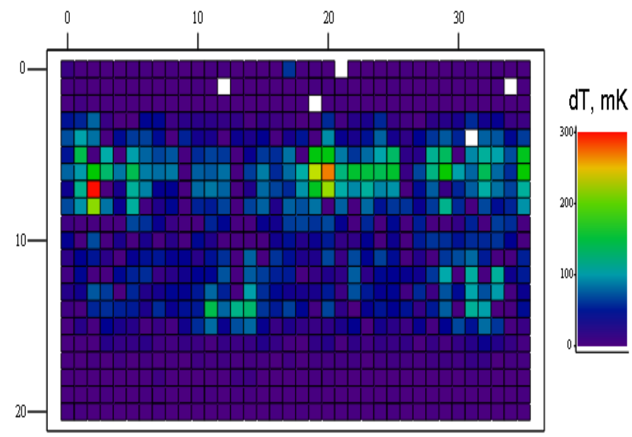

Figure 2: The temperature map before 100°C baking at 110 mT. Row No.10 corresponds to thermometers located around equator, rows No.1 and No.19 correspond to top an bottom iris accordingly

DISCUSSION

In connection with these experiments we want to discuss an important question about the cause of the high field Q-slope: is the high field Q-slope caused by high surface electric or high surface magnetic field? If the high field Q-slope is caused by high surface electric field, then new shape cavities, such as low loss shape and re-entrant shape[2,3], are a dangerous way to higher accelerating gradients. The new shape cavities have higher ratios of peak surface electric field to accelerating gradient. Higher surface electric field would cause earlier onset of high field Q-slope and stronger slope.

Our thermometry data clearly show that high field Q-slope is caused by high magnetic field. In every test, where we didn't have field emission, every temperature map shows that at high fields most heating happens near equator, where magnetic field is strong.

We compared readings of a thermometer as a function of field in the high magnetic field regions and readings of

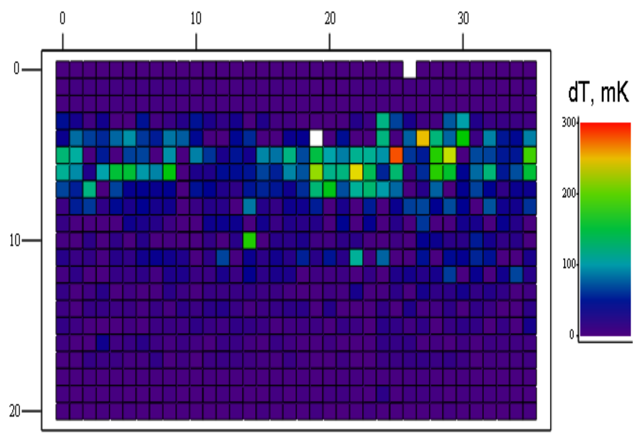

Figure 3: The temperature map after 100°C baking at 130 mT.

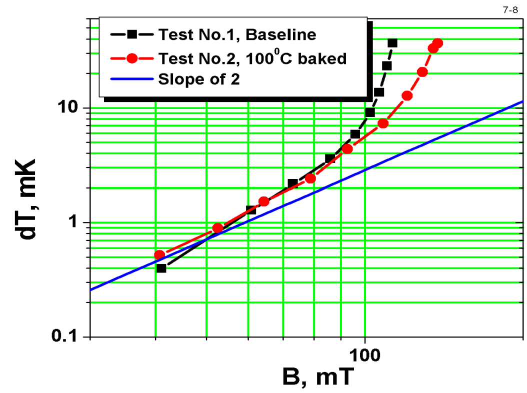

Figure 5: Reading of a thermometer near equator as a function of the peak surface magnetic field (high surface magnetic field).

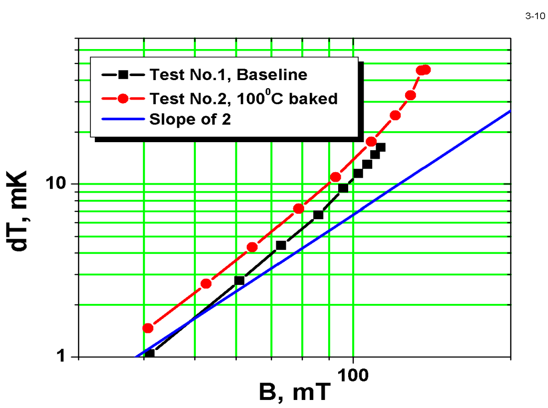

Figure 4: Reading of a thermometer near iris as a function of the peak surface magnetic field (high surface electric field).

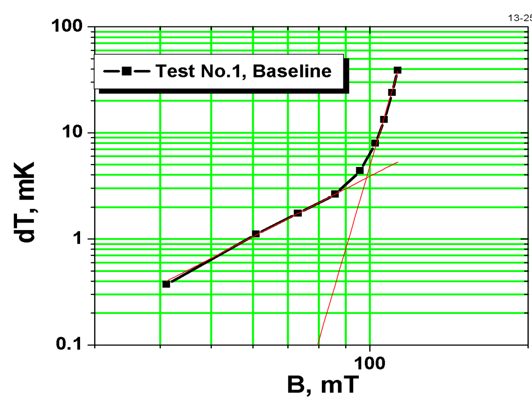

Figure 6: Readings of one thermometer.

a thermometer in high electric field regions. Thermometers in high electric field regions show no high field Q-slope both before baking and after baking. We account for the slight change in slopes at high fields by bath temperature growth, induced by other regions of high field Q-slope (Fig.4.). On the contrary, thermometers in high magnetic region show rapid increase in losses similar to high field Q-slope seen in quality factor versus field plots (Fig.5.).

Now we want to focus on the readings of a thermometer as a function of field. The whole curve can be described by four numbers: initial value at low field, medium field slope, onset field value and high field slope (Fig.6.). And we will consider all thermometers from the same row. Since all thermometers from the same row see the same local surface field, it makes sense to calculate mean values of high field slopes, medium field slopes and intersection points for given row and then plot these mean values as a function of row. We calculated these values for our first test with chemically polished cavity before baking. In Fig.7. we plot the mean values of the high field slope as a function of thermometer's vertical position. Also in this graph you see cavity shape (black line, arbitrary units), square of magnetic field (red line, arbitrary units) and square of electric field (deep blue line, arbitrary units). One can see some correlation between the distribution of magnetic surface field squared and that of the high field slopes. On the other hand medium field slopes are independent of thermometer's position and in that test they were around 2.5 for most thermometers (Fig.8.). One likely explanation that the slope at medium field is higher than 2 is because of thermal feedback effect. We also calculated the distribution of the high and medium slopes after baking. There is almost no change in the medium slope's values compared to those before baking (Fig.10.). But high field slope's values became smaller from 5-25 before baking to 5-10 after baking (Fig.9.). Again there is a correlation between magnetic field distribution and the high field slopes' distribution.

Strong evidence in favor of magnetic field theory was found by G.Ciovati et al.[4]. They measured a cavity's performance in TE_{010} mode. In this mode electric field

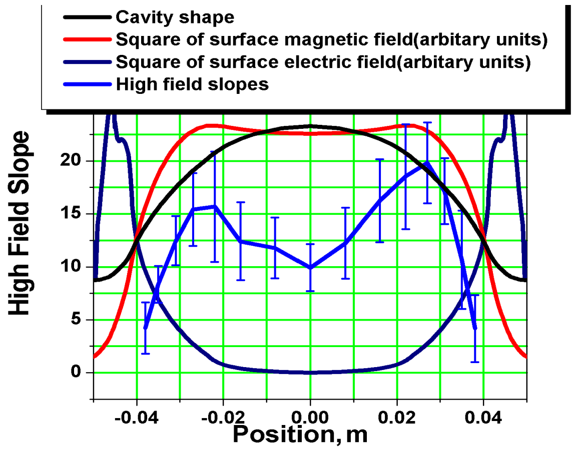

Figure 7: Distribution of high field slopes before baking.

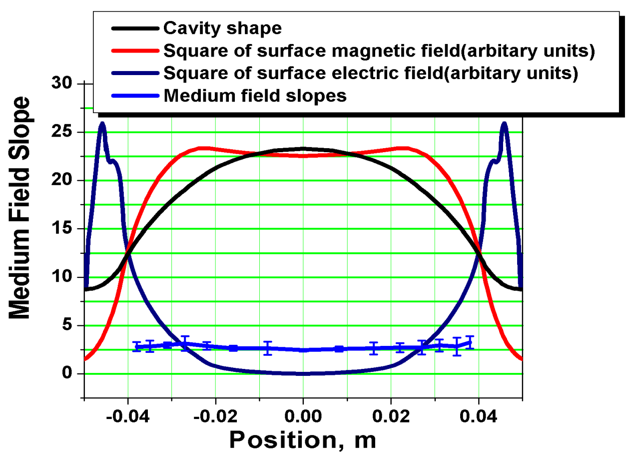

Figure 8: Distribution of medium field slopes before baking.

is equal to zero on the cavity surface. Nevertheless the cavity still had a high field Q-slope. Only magnetic field could cause losses in this case.

Next we want to address the question about uniformity of the high field Q-slope. Temperature maps that were taken at high fields show an uneven distribution of heating, for instance Fig.2. It is possible to distinguish between "hot spots" which have a tendency of being located in the high surface magnetic field regions and "cold spots". The localized behavior of power dissipation suggests that the high field Q-slope effect is not uniform and that it can be attributed to some local inhomogeneities in the cavity surface. But let us clarify what the high field Q-slope is. We define a high field Q-slope as anomalous losses in the cavity surface unlike quadratic losses at medium fields. Anomalous losses can be seen as a rapid drop of quality factor at high fields or in thermometry data as a rapid increase in temperature readings, which at high fields are not quadratic with field, but can go as steep as field in power of 20. In the Fig.7,9 we see that value of the slope is determined by vertical position of the thermometer. For example even

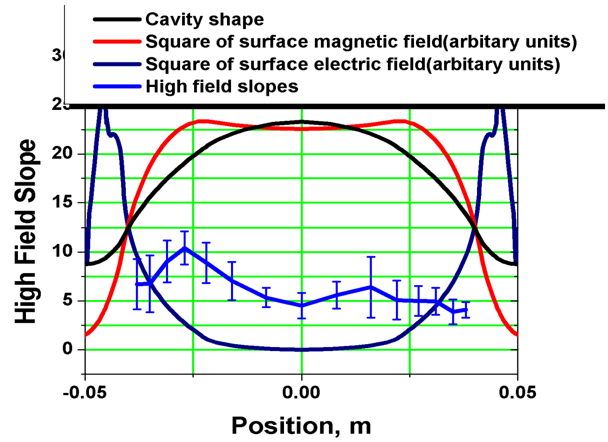

Figure 9: Distribution of high field slopes after baking.

though the absolute value of temperature rise can be different around the cavity for thermometers in row 9 (3 cm from equator) (Fig.7.), all these thermometers have a high field slope's value more than 9. Thus we see that even though the temperature distribution is not uniform in the temperature map (Fig.2.), and some areas dissipate more than others, nonetheless *all areas have anomalous losses at high fields*.

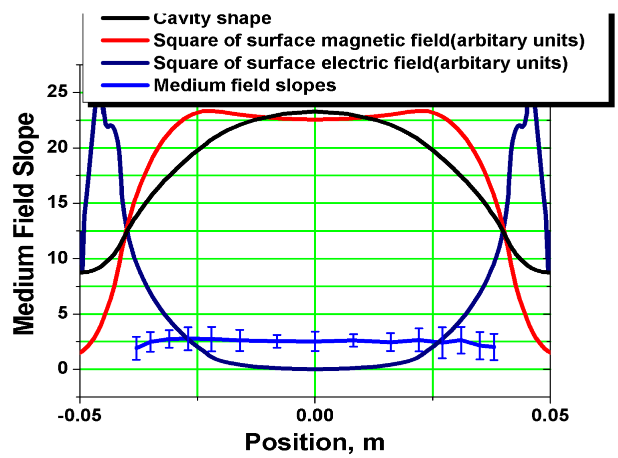

Figure 10: Distribution of medium field slopes after baking.

From this we conclude that every spot of the cavity surface has a high field Q-slope, thus the high field Q-slope can be attributed to the general niobium properties rather than to some localized defects.

An interesting observation is a drop in the mean value of the high field slope at the equator. In spite of the fact that magnetic field varies only by a few percent from highest value to the value at the equator, the slope value in the equator is definitely lower. We suspect that high field slope is lower in the equator, because grains are larger in the weld and niobium is purer. This is consistent with the large grain cavity results[5]. In these experiments it was shown that cavities with larger grains have weaker high field Q-slope.

We finish this discussion with plotting readings of three thermometers: one from "hot region", one from "cold region" and one from high electric field region, from baseline test with LE1-30 (Fig.11.). Note that the onset field of the Q-slope in hot and cool spot are compatible.

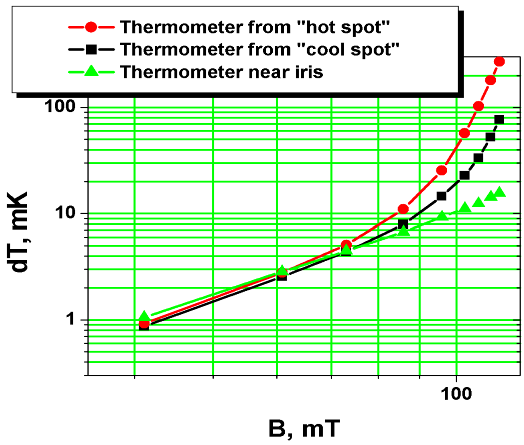

Figure 11: Comparison of thermometers from different regions.

CONCLUSION

Our thermometry data clearly show that high field Q-slope is caused by high magnetic field and should be attributed to general properties of niobium rather than to some localized inhomogeneities. The strength of the Q-slope shows a correlation link to B^2. The distribution near weld region shows a weaker Q-slope most likely due to fewer grain boundaries.

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