EXPERIMENTAL INVESTIGATIONS OF THE QUENCH PHENOMENA FOR THE QUENCH LOCALIZATION BY THE SECOND SOUND WAVE METHOD

J. Plouin*, J.P. Charrier, C. Magne, L. Maurice, J. Novo, CEA-Saclay, Gif-sur-Yvette, France

Abstract

The quench localization by the second sound method is now widely used in many laboratories. This method avoids the complicated implementation of temperature arrays around the surface cavities. Instead, specific sensors are placed around the cavity and the time of arrival of the second sound wave generated by the quench is measured on each sensor; then the distance from sensors to quench is deducted from the theoretical second sound wave velocity. In principle, the quench position can be localized with a triangulation by a limited number of sensors.

However, many measurements have shown that the time of arrival of the wave was not corresponding to the theoretical second sound wave velocity: the "measured" velocity is often 50% higher than the theory.

At CEA-Saclay we performed several measurements on single cell cavities to investigate these phenomena. Several hypotheses are studied: large quench spot, heat propagation by another phenomenon than the second sound near to the cavity where the heat power density is very high.

These results and the discussions on these hypotheses are presented hereafter.

OVERVIEW

The search for of high accelerating fields and for large scale fabrication (XFEL, ILC…) requires simple methods to localize the quench position in a cavity, in order to proceed to reparation. The second sound technique could be a nice solution and is based on the following principle [1]. A heat pulse is generated by the quench spot. In superfluid helium (T<2.17 K) this heat pulse is transported through a second sound wave, which is a quantum phenomenon [2]. The arrival of this wave on Oscillating Superleak Transducters (OSTs) is measured by an electric signal induced by the deformation of the OST flexible membrane.

QUENCH LOCALIZATION AT CEA

At CEA-Saclay, we used monocell 1.3 GHz cavities to test this technique. The tests were performed in the vertical cryostat "CV2" in the Supratech platform of CEA. Each cavity was equipped with a temperature mapping system, and 4 OSTs, provided by Cornell, were placed around the equator plane.

The temperature mapping consists into 17 thermometers fixed on a structure able to rotate around the cavity axis.

Each OST is connected to an electronic circuit which provides a 120 V polarization, amplifies and filters the signal (Fig. 1).

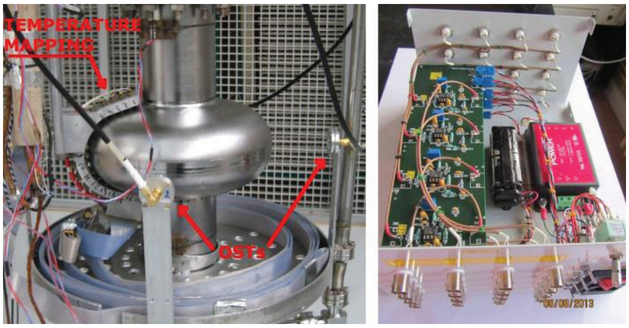

Figure 1: 1.3 monocell cavity equipped with temperature mapping and OSTs (left) and electronic circuit dedicated to OSTs (right).

Cavities Performances

We could realize five tests where the thermal quench was reached without electron emission: two tests with Cavity A and three tests with Cavity B. The Q_0/Eacc curves are shown in Fig. 2; Cavity A reached 30 MV/m twice and Cavity B reached 34 then 36 and 37 MV/m. The helium bath temperature was around 1.5 K for Cavity A and around 1.6 K for Cavity B.

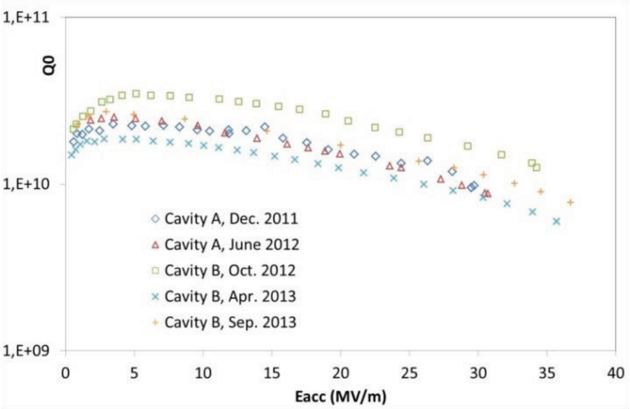

Figure 2: Q_0/E_{acc} curves of the tested monocell cavities.

Quench Localization with Temperature Mapping

The quench position was localized with the temperature mapping, to have a reference comparison with OSTs measurements. The position is determined with a precision of a few millimetres in each direction (Fig. 3).

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*juliette.plouin@cea.fr

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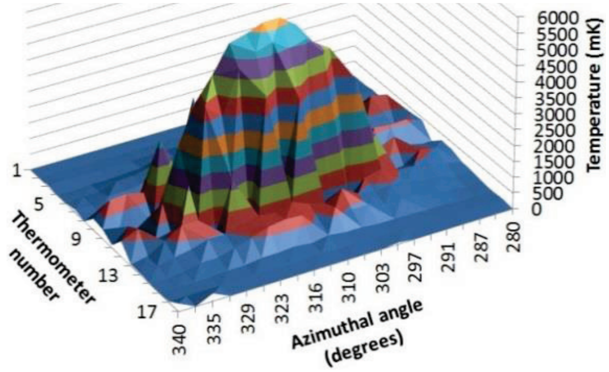

Figure 3: quench localization with temperature array (cavity A, Dec. 2011). The quench is positioned on the equator (thermometer 9).

OST Measurements

For each test, we then placed the temperature mapping system on an azimuthal position opposite to the quench to avoid perturbations, and we measured the signals from OSTs during a series of quenches. The results were recorded by an oscilloscope trigged by the RF quench signal, given by the RF power reflected by the cavity (blue positive step signal on Fig. 4). The signals from OSTs always start with a sharp negative decrease, caused by the arrival of the second sound wave on the flexible membrane. The time of arrival of the wave on each OST after quench trigger can be measured with a precision less than 100 µs.

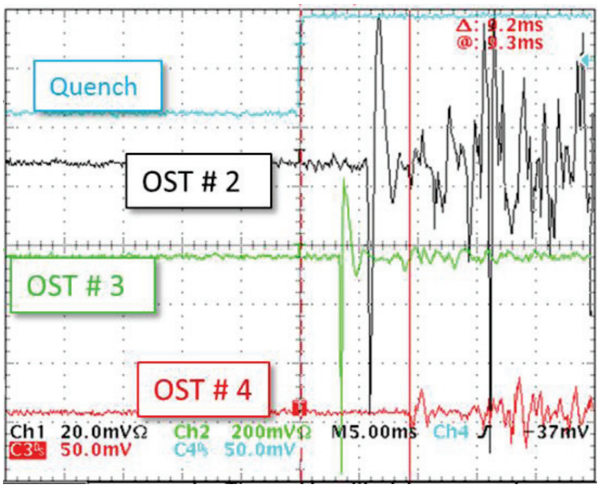

Figure 4: Oscilloscope signals during quench with OST signals.

In principle, the quench position is then localized by multiplying the time of arrival by the velocity of 2nd sound, which is equal to 20 m/s or less between 1.4 and 1.8 K [3]. Then, one can trace spheres with radius equal to this quantity, and their intersection with the cavity should give the quench position. However, doing this leads in general to trace spheres whose radii are too small to reach the quench location, even sometimes the cavity.

Two examples are given in Fig. 5 for the two tests with Cavity A, where the quench was found on the equator by the temperature array. Since the OSTs are also in the equator plane, the problem can be treated in two dimensions, using circles instead of spheres.

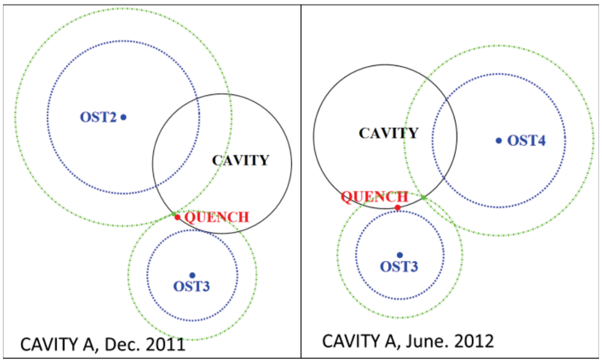

Figure 5: tentative triangulation in the equator plane with 2nd sound velocity equal to 20 m/s (blue circles) and to 28.5 m/s (green circles).

"Too Fast" Second Sound Wave

One can see that the blue circles don't intersect. We found the same kind of results for the three tests with Cavity B, except that the quench was not on the equator.

The results can be presented as follow: for each test, and for the two nearest OSTs, the distance (quench-OST) has been divided by the time of arrival of the signal. The result is the corresponding velocity of a wave that would travel from the quench point to the OST.

Table 1: Calculated Velocities for the Wave Travelling from Quench to the two nearest OSTs

Test	Cavity	Eacc at quench	v first OST	v second OST
Dec 2011	A	30 MV/m	27 m/s	30 m/s
June 2012	A	30 MV/m	22 m/s	36 m/s
Oct 2012	B	34 MV/m	39 m/s	28 m/s
Apr 2013	B	36 MV/m	31 m/s	26 m/s
Sept 2013	B	37 MV/m	34 m/s	27 m/s

During the test of Apr 2013, we also measured OSTs signals during the cooling of the helium bath around the cavity.

The result is shown on Fig. 6, with the calculated velocity (like in Table 1) corresponding to the two closest OSTs.

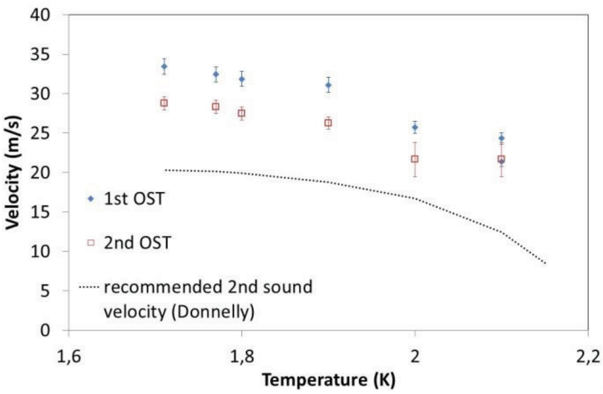

Figure 6: Calculated velocities for the wave travelling from quench to the two nearest OSTs with varying temperature.

From Table 1 it is clear that the "measured wave velocity" is always higher than the theoretical 20 m/s.

Figure 6 shows that this "measured velocity" evolves with the same shape as the theoretical one, but has always higher values.

Thus, considering the heat transportation in helium as a pure 2^{nd} sound wave traveling from a point seems to generally lead to a "too fast" 2^{nd} sound wave. Similar results were also found by other laboratories [4, 5].

DISCUSSION

Triangulation with Mathematical Function

Some better localization can be achieved by using the 2^{nd} sound wave velocity as a fitting parameter v_2. [1]. One can then minimize the following mathematical function, and force the resulting point to be on the cavity surface.

$$\sum_i ((x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 - (v_2 * t_i)^2)^2$$

The parameters x_i, y_i, z_i and t_i represent the position and the time of arrival of each OST. This method is used by several labs to proceed to quench localization [4, 6].

By using this technique in two dimensions for the two tests with Cavity A, and only with the two OSTs that are directly seeing the quench, we had to use 28.5 m/s as a parameter for the wave velocity. The quench localization with this technique (green dots on Fig. 5) is quite good for the Dec. 2011 test, but quite imprecise for the June 2012 test.

Finally, this triangulation technique, conjugated to a large number of OSTs, can lead to localization around a few cm, which is already a good reduction of the area to observe.

However, all these observations highlight that the phenomena involved during a quench cannot just be described by the generation of a 2^{nd} sound wave by a point source. One can give two explanations:

- The heat source formed by the quench is not a point.
- The heat propagation is not carried by a pure second sound wave.

Size of the Quench Spot

The thermal quench of a cavity is generally caused by a local increase of the magnetic field on a small defect situated on the inner surface of the cavity. On the outer surface, the heat source is rather a spot, with a size depending on the dynamic of the heat propagation in both niobium and superfluid helium. If the size of the spot is a few cm, one can understand that the signals arriving on different OSTs come from different points of the spot, each being closer to the OST than the position of the defect. Then the "measured wave velocity" is overestimated, which is coherent with what we observed. This "large spot" quench has been studied in several laboratories. [4, 7].

No Pure Second Sound Wave

However this "large spot" hypothesis is not enough to explain the observed phenomena, since it even occurs that a sphere traced from OST with a radius equal to [time of arrival of the wave]x[theoretical 2^{nd} sound wave] don't even intersect with the cavity surface.

Actually, it seems that heat propagation from niobium to OST is more complicated than a pure 2^{nd} sound wave. Figure 3 shows that the temperature near the quench reaches more than 5 K, higher than the lambda point of helium (2.17 K). The nature of heat propagation is determined by the surface power density, and above a given value, 2^{nd} sound waves cannot propagate [8, 9]. Thus it seems that during quench tests, we cannot consider the heat propagation as a "pure" 2^{nd} sound wave.

Further Developments

To get rid of the size of the spot, as well as to control the surface power density, it is very interesting to simulate a quench with a specific heater. Such experiments have already been developed [5, 10-12], and we would like to reach higher values of heat power surface density to investigate whether the 2^{nd} sound wave disappears, at least locally, when the power is grown up.

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