SECOND SOUND AS AN AUTOMATED QUENCH LOCALISATION TOOL AT DESY*

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Abstract

The understanding of the origin of local thermal breakdown („quench") in superconducting RF cavities is still a challenge. Such heat spots can be conveniently measured using the second sound in superfluid helium. This detection technique has been examined in several institutes. At DESY there are currently two vertical bath cryostats where cold RF tests with a cavity mounted in a cryostat insert can be done. At all of the four inserts the second sound setup consisting of eight Oscillating Superleak Transducers (OSTs) is mounted. These are connected to amplifier electronics and the measured signals are fed into an ADC to be read out with MATLAB[†]. Within MATLAB the location is derived from the measured propagation times. The present system is already in use on a regular basis. For the efficient testing and diagnosis of a large batch of cavities such as the 1.3 GHz cavities (see Fig. 1) for the European XFEL [1] and the International Linear Collider ILC [2], fast diagnostic tools are mandatory. An automated setup which will be implemented into the routine RF measurement procedure is under development.
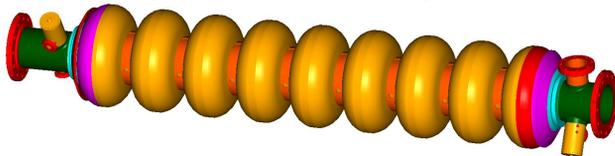
Figure 1: 1.3 GHz 9-cell superconducting RF cavity.

QUENCH LOCALISATION METHODS

A quench may arise from impurities or irregularities in the superconducting niobium, which will cause a temperature rise until the critical temperature T_C of the niobium is reached and a quench is induced. The heat deposited in the niobium and subsequently in the helium bath can be detected by thermometers attached on the outer cavity surface, the so-called temperature mapping ("T-Map") [3]. Another possibility is the use of the second sound, a phase-transition wave induced by depositing heat into the superfluid helium bath [4]. This quench localisation method is much faster than T-Map, since it omits the mounting procedure of the sensors, and one quench is sufficient to detect the quench location.

AUTOMATION OF QUENCH LOCALISATION USING SECOND SOUND

Second Sound Detection

The second sound in liquid helium can be detected with condenser microphone-like Oscillating Superleak Transducers as shown in Fig. 2.

Figure 2: Picture of an OST in use at DESY (and in other institutes).

Liquid helium cooled below the λ-point can be described as a mixture of two fluids, He-I and He-II. As He-I cannot propagate through the thin porous membrane of the OST, it exerts pressure on the membrane which changes the capacity of the OST. This change is detected by the voltage-variation at the device. A schematic drawing about this process is shown in Fig. 3.
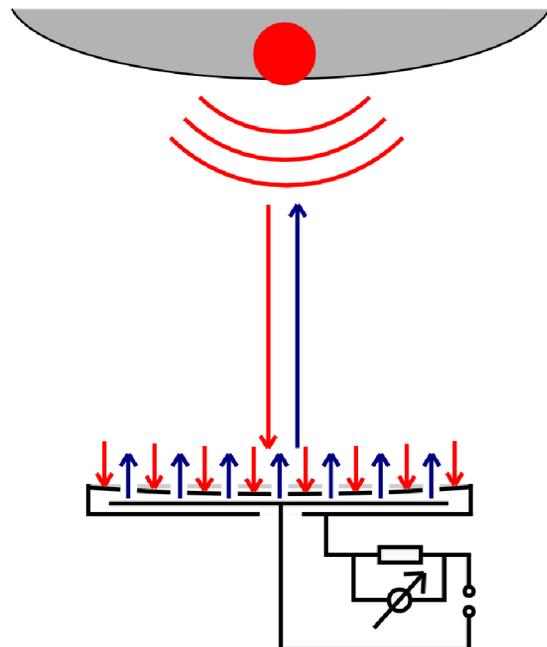

Figure 3: Schematic drawing of the second sound detection with an OST. He-I (red) is "blocked" by the porous membrane and exerts pressure, while the counterflow of He-II may pass the membrane easily.

Data Acquisition

For an ideal measurement, all eight OSTs record a second sound signal after quenching. A 16 channel multiplexed USB-ADC with 250kS sampling rate, as variable and mobile device is used for the data acquisition in combination with a simple MATLAB code. With a propagation velocity of ≈20 m/s and distances below 1 m a time of about 50 ms has to be recorded. Currently the reflected rf signal, the eight OSTs and a reference electric line for noise reduction are sampled with 10 kHz which results in a propagation of ≈2 mm per data point for the measurement. The total accuracy is of the order of 10 mm. An example of a full data set is given in Fig. 4.
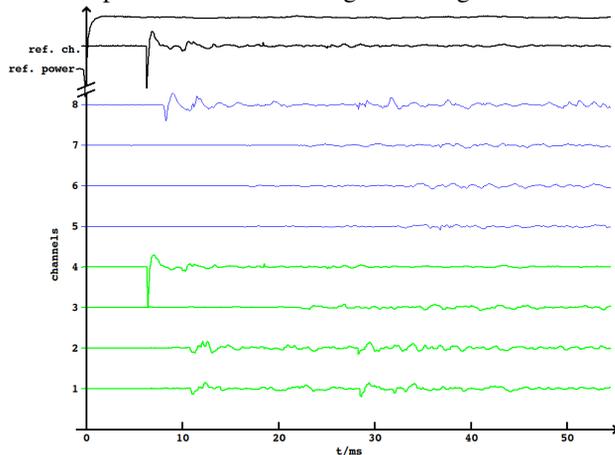

Figure 4: Second sound data set from cold rf test of cavity AC156, test 3, pi-mode. The black signals are the reflected power and the strongest OST signal as reference. The channels highlighted in green will be used for calculating the quench location, the blue ones are for completeness. Channel eight was not chosen since this OST is not in line-of-sight of the quench, as determined from the other propagation times.

Data Evaluation

To calculate the propagation times, the time of quench is needed. It is derived from the reflected RF power P_{ref}, which rises strongly when a quench occurs.

If the signal-to-noise ratio is not sufficient, a second set of data is acquired by switching the rf signal off, since noise from the ground of the measurement rack is fed through to all the signals. This switch reduces the noise significantly, so the largest signal of the first data set can be found in the second set as well as a reference for the propagation time calculation.

With the determined quench time it is possible to specify the propagation times to the different OSTs. Using the quench time and knowing the characteristics of the OST signal – the voltage will drop when the wave arrives – the propagation times are determined manually. First tests of an automated fitting and recognition MATLAB code have been successful.

The next step is the choice of the OST signals for the quench localisation. Usually the quench occurs in the equator area, so 4 OSTs with direct line-of-sight are used for the calculation. In the example in Fig. 4 the channels 1 to 4 are the OSTs of choice.

Quench Localisation

The OST positions have been measured before the vertical test and are used in the calculation. As the distances travelled by the second sound towards the OSTs are known, spheres with the radii of these distances can be drawn from the OST locations, as shown in Fig. 5. In the intersecting volume of these spheres the quench has its origin. This geometric approach is carried out with a least squares fit in the localisation code [5].
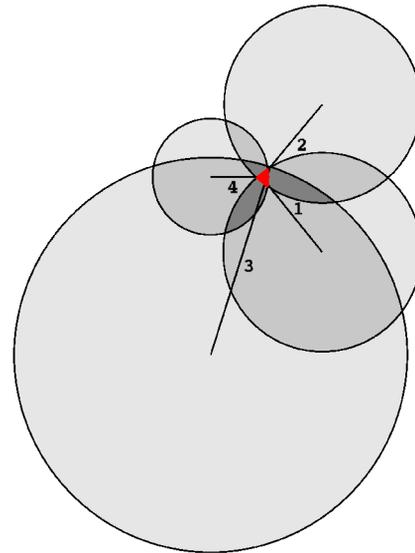

Figure 5: Spheres including the distance propagated by second sound. The intersecting volume is the most likely quench location.

This calculation may lead to a position not located on the surface of the cavity within measurement uncertainty. Thus, using the geometric surface of the cavity as a constraint, the least squares fit is refined. The result of the formerly introduced example shows the quench location to be slightly below equator 6 at approximately 285° as shown in Fig. 6. More details about this cavity series and test results can be found in [6].

Data Analysis

The verification of the located positions can be made with mode measurements of the cavities which excites maximum fields in different single cells. More details and comparison of second sound results with these mode measurements are shown in [7].

Another possibility is the optical inspection of the inner cavity surface before or after the vertical test [8]. Combining the knowledge of the quench location and the corresponding picture of this position within the cavity

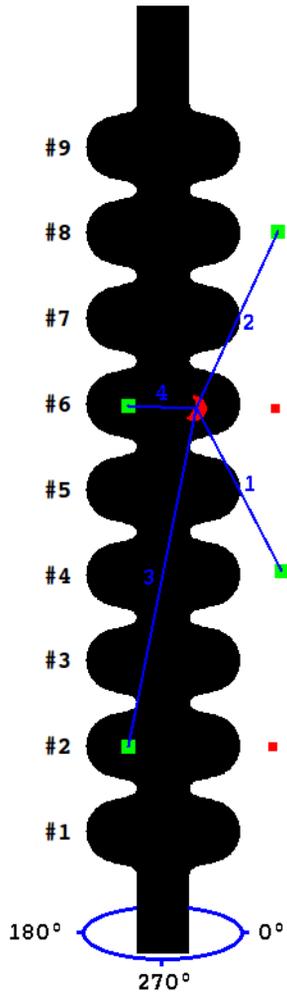can lead to a better understanding of the quench phenomenon.

Figure 6: Plot of a 9-cell cavity with the positions of the OSTs marked with squares. The green OSTs are the used ones for the determination of the quench location and the blue lines point to the quench location as calculated with the MATLAB code.
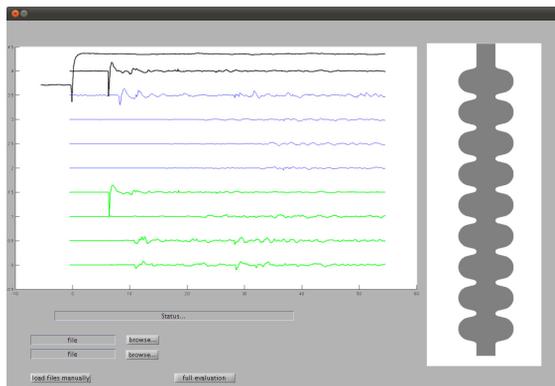

Figure 7: The current version of the graphical user interface (GUI) for the second sound measurements at the vertical test stands at DESY.

SUMMARY AND OUTLOOK

The use of second sound is an easy way to determine the origin of the thermal breakdown of a SCRF cavity. A simple hardware setup similar to [9], but modified for the needs of vertical tests on a large scale has been implemented at the vertical rf test stands at DESY.

Software modules for the automated quench localisation are already available and were introduced in this paper. A first draft of the graphical user interface combining all these modules to a software to be handled by the rf test operator is shown in Fig. 7.

First tests and full second sound measurements at one cryostat insert were done in 2010. Since the beginning of 2011 the second sound measurement setup is in regular use as the final equipment of all four cryostat inserts has been completed, see Fig. 8. Up to the end of June 2011 fourteen cavities have been tested with the current setup and the results obtained with temperature mapping (if available). The comparison with the mode measurements is very good.
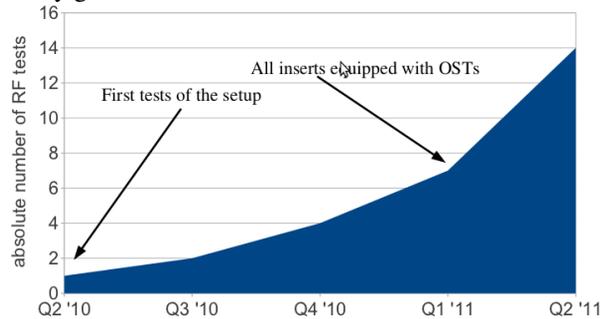

Figure 8: Timeline of RF tests done.

ACKNOWLEDGEMENTS

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