SECOND SOUND MEASUREMENT USING SMD RESISTORS TO SIMULATE QUENCH LOCATIONS ON THE 704 MHz SINGLE-CELL CAVITY AT CERN

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Abstract

Oscillating Superleak Transducers (OSTs) containing flexible porous membranes are widely used to detect the so-called second sound temperature wave when a quench event occurs in a superconducting RF cavity. In principle, from the measured speed of this wave and the travel time between the quench event and several OSTs, the location of the quench sites can be derived by triangulation. Second sound behaviour has been studied through different surface mount (SMD) resistors setups on a Superconducting Proton Linac (SPL) test cavity, to help understand the underlying physics and improve quench localisation. Experiments are described that have been conducted to search for explanation of heat transfer mechanism during cavity quench that causes contradictory triangulation results.

INTRODUCTION

Second sound is an interaction between the superfluid and normal fluid components in superfluids when heat transfer takes place in superfluid liquids. Extensive research on this quantum phenomenon has been conducted since the liquefaction of helium in 1908. The travel speed of this wave is ~ 20 m/s at 1.8 K. This is a key parameter in cavity quench triangulation along with the measured travel time of this wave to a dedicated OST detector.

Nevertheless, problems have been encountered such as non-responding OSTs in liquid helium and triangulation results not matching quench locations, either by use of experimentally or theoretically determined second sound velocity (both ~20 m/s) [1-3]. On the other hand, a second sound velocity consistent with theory has been measured by using SMD thick film resistors as heat source at CERN. These studies have been carried out to understand this heat transfer phenomenon and OST characteristics for improvement of cavity diagnostics [4].

This paper describes an extensive investigation using SMD resistors on a single cell elliptical SPL test cavity as simulated quench spots as well as on their own in a cryostat [4]. OST positioning on the cavity is discussed and a possible explanation and solution for common problems encountered during cavity quench detection will be described.

The paper is arranged in four parts. First, experimental setups and measurement procedures are introduced. Second, OST mounting and testing techniques for improving signal capture performance are presented. Third, a cavity quench event is analysed and results in searching for possible explanations are discussed. A summary and a direction for ongoing work conclude the paper.

EXPERIMENTAL SETUP

Two types of setups are used: (1) Cavity-SMDs-OSTs setup for simulated quench studies and RF cavity quench test and (2) SMDs-OSTs only setup for second sound characteristics studies [4]. In a simulated quench test, 27 quench locations are provided on a cavity (Fig. 1). All resistors are from the same batch with dimensions 1.6 (L) x 0.8 (W) x 0.45 (H) mm^3, 1/10 W, ~67 Ω at 1.7~1.8 K. Two OST supports each cover 120º of the cavity circumference. Each is equipped with 3 extendable vertical and 0 ~180º horizontally adjustable screws that fix onto pivots (Fig. 2(a)). This can be set to the desired height around the cavity. Three OSTs are mounted at the equator region, three at the iris and two on a cavity supporting rod for reference (Fig. 2(b)). An RF cavity quench was captured with the same setup and this will be discussed later.

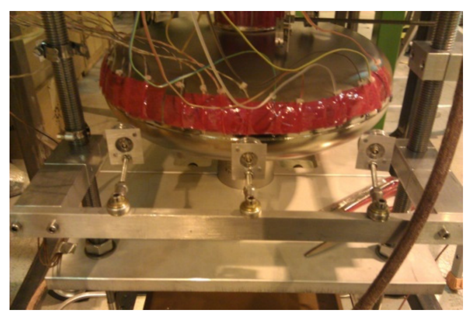

Figure 1: SMDs are distributed around the equator, iris and other surfaces corresponding to different OSTs as in Fig. 2(b).

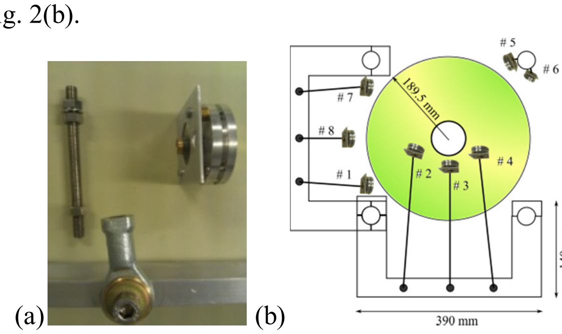

Figure 2: (a) The aluminium OST support can be mounted to a desired height and the three extensions holding their OSTs are adjustable towards the cavity (b) Three OSTs each govern ¼ equator area and another ¼ iris region respectively. Two OSTs are mounted on a rod supporting the cavity with # 5 facing the equator and #6 is 9.3 cm above #5.

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Measurement Procedure

A pulse of fixed length and voltage is generated from a function generator to the SMDs to imitate a quench event. Due to the limitation of maximum 10 V that a common function generator can deliver, a CERN-made device is used to deliver larger power to the SMDs.

STUDIES FOR SECOND SOUND DETECTION IMPROVEMENT

To avoid OST malfunction when the setup is brought down to cold environment, a room temperature microphonic test is carried out each time. This is simply done by clapping around the OSTs and the first sound signal can be seen on an oscilloscope.

OST Arrangement

A distance dependence measurement was done using an adjustable OST insert measuring 2 cm ~ 20 cm right above an SMD resistor [4-5]. Unanimous results from several distance variation tests show that the second sound amplitude is at its maximum – ~ 9 cm above the heater source. When the distance is doubled to 18 cm, the signal loses 60% of its amplitude (Fig. 3). Therefore, care should be taken to mount OSTs with respect their cover range along with other factors [4].

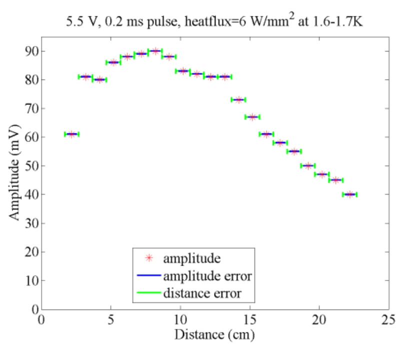

Figure 3: A distance variation measurement shows maximum amplitude detected by an OST at ~9 cm distance from the heater.

OST Blind Spots & Second Sound Reflection

SMD heaters simulating quench locations are placed near (1) the equator region (2) the irises and (3) other nearly flat half-cell areas on the test cavity with corresponding OSTs mounted (1) in and (2) outside the heater's line of sight (Fig. 1). It is found that when the heater is located on a spot outside the OSTs' membrane coverage angle, the second sound signal is never observed.

Nevertheless, reflection-like behaviour was seen in a series of measurements with tubes. Three tubes (I, J, and U shaped) with almost the same diameter and length were tied underneath a common OST (Fig. 4). Second sound was detected from all three heaters. The amplitudes of the signals which went through the bent tubes were significantly attenuated compared to the straight tube (I). This concludes second sound can be reflected at a Nb surface. Therefore, quench spots on structures more complicated than elliptical cavities such as the Quadrupole Resonator [6], which quenches at 80 mT (peak) should be detectable with OSTs.

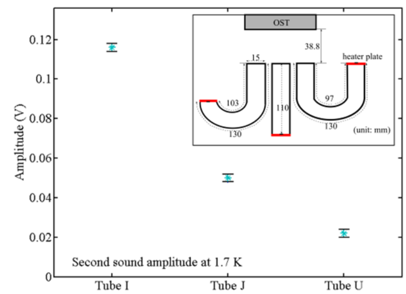

Figure 4: Second sound is detected with amplitude attenuation through tubes having bent structure.

OST Protection Caps

The membrane on each OST is fragile and they have experienced damage and pollution during setup modification and installation. Therefore, dedicated OST caps were made of silicone to protect against risks that influence second sound detection. As shown in Figure 5, a gap is left to avoid the bottom of the cap touching the membrane.

Figure 5: OST protection caps are made to protect membrane against damage or pollution during the mounting process.

QUENCH EVENT ANALYSIS & FAST SECOND SOUND

Cavity Quench and Triangulation

A cavity quench event at 3.1 MV/m, 36 mbar (~ 2 K) on an SPL test cavity during helium processing was first detected while the setup used for simulation quenches remained. The reason for the accelerating field peak that goes up to 8.3 MV/m within 6 μs is under investigation (see Fig.6). It is to note that the breakdown time is at only ~ 28 μs.

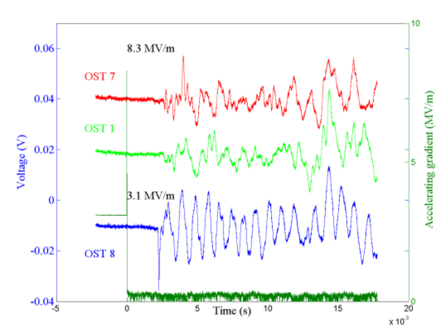

Figure 6: A quench detected by three OSTs.

Second sound velocity at 16.8 m/s is taken as a fitting parameter at 2 K for triangulation. However, the three circles constructed do not intersect at a common point, not even on the cavity surface (Fig. 7). This implies that the detected wave travelled at a faster-than-second-sound speed. It could possibly be a mixture of other forms of heat transfer [7] when superfluidity was destroyed due to a large amount of heat. A minimisation method proposed by Maximenko and Sergatskov [1] is used along with cavity surface constraints [3] for quench localisation (Fig. 8(a)). A speed of ~ 30 m/s is retrieved to locate the quench spot by this method.

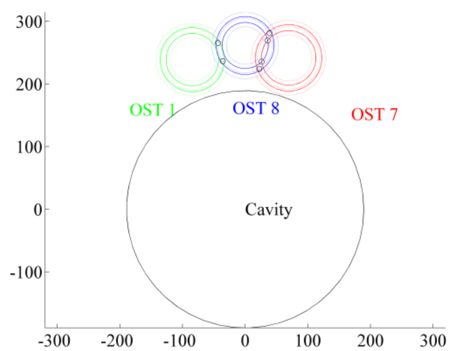

Figure 7: Circles constructed by second sound velocity 16.8 m/s at ~ 2 K and with error bar constructed circles.

Nonetheless the reconstructed 30 m/s triangulation circles showed an area surrounded by their intersections rather than a single point (Fig. 8(b)). It seems that when quench occurs, the mechanisms involved during heat transfer do not travel at a constant speed.

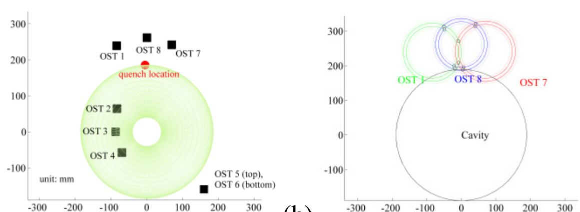

Figure 8: Quench localisation by using a minimisation method (a) and (b) intersection area using a 30 m/s parameter retrieved from the minimisation method.

Search for Fast Second Sound

Experiments have been done to search for 'fast second sound' quench phenomenon by sending maximum power into an SMD heater and arranging two OSTs facing sideways to the heaters and an OST 90 mm above (Fig. 9). However, the behaviour of 'fast second sound' had not been seen by using SMD heaters because of a relatively small heat flux received at the OST compare with that of a real quench situation. The dissipated power during our quench event is a lot higher than the simulated experiments. Therefore, appropriate sources with small dimensions that can withstand high power input should be investigated.

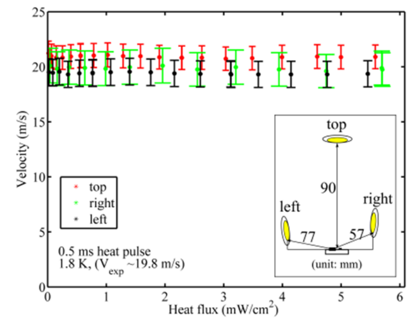

Figure 9: Response of OSTs at the top of the heater and two OSTs on the sides when power is increased to deliver to the heaters.

SUMMARY & FUTURE WORK

Studies using SMD resistors and OSTs have been carried out to improve understanding and detection of the second sound wave. These include a microphonic test done prior to the cool-down process and suggestions on how to place OST detectors around a cavity. The OSTs have observed second sound reflection. This makes them applicable for complicated cavity structures. A cavity quench event occurred on a single-cell SPL test cavity was observed during helium processing. Nevertheless, SMD simulation experiments could not confirm a faster-than-second sound phenomenon detected in this cavity quench due to incomparable power dissipation. For future investigations, it is then crucial to search for improved sources to simulate in order to better replicate the heat transfer mechanisms. Cavity quench tests on the SPL test cavity will be continued after an electropolishing process. Furthermore, OST configurations for new five-cell SPL cavity prototypes are to be examined.

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