

SECOND SOUND QUENCH DETECTION OF DRESSED TESLA-SHAPE SRF CAVITIES

Y. Tamashevich*, University of Hamburg, Hamburg, Germany
E. Elsen, A. Navitski, DESY, Hamburg, Germany

Abstract

A compact detector and numerical algorithm for second sound measurements has been developed. The detector allows precise 3D quench localisation within a single unit and can be used even for cavities with mounted helium tank. The compact device is easily mounted and requires minimum space. It can be used as a part of the standard cold test of cavities. The results obtained with the new detector and a 3D algorithm have been cross-checked by optical inspection and resistor-based temperature mapping. The resolution of the detector is seen to be limited by the sampling rate and the lateral extent of the quench induced heated area on the Nb superconductor.

MOTIVATION

Sudden heat deposits such as induced in a quench of a superconductor produce a second sound wave in the surrounding helium bath when operated below the λ -point. The second sound propagates at velocities of ≈ 20 m/s which makes it conveniently accessible to measurements of propagation delays [1]. The second sound wave propagates without much attenuation over distances of several meters.

An additional challenge arises in restricted areas such as the 9-cell cavities used for the European XFEL. The helium tank of the E-XFEL cavity has one opening with a diameter of 56 mm with the two-phase gas return pipe attached. So the sensors can be placed only in this opening (Fig. 1).

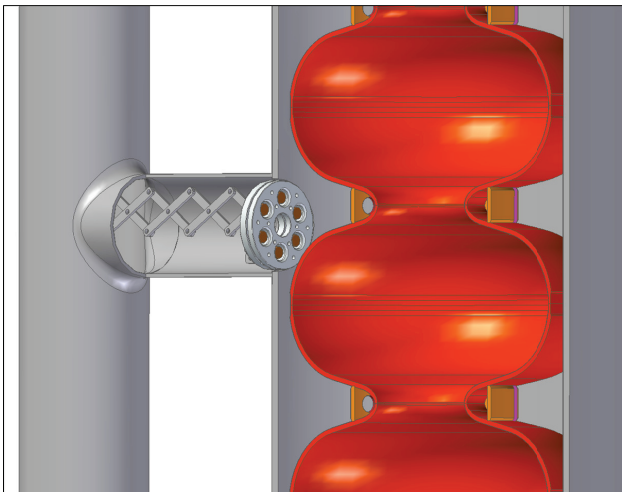


Figure 1: MultiOST detector installed inside the helium pipe.

* yegor.tamashevich@desy.de

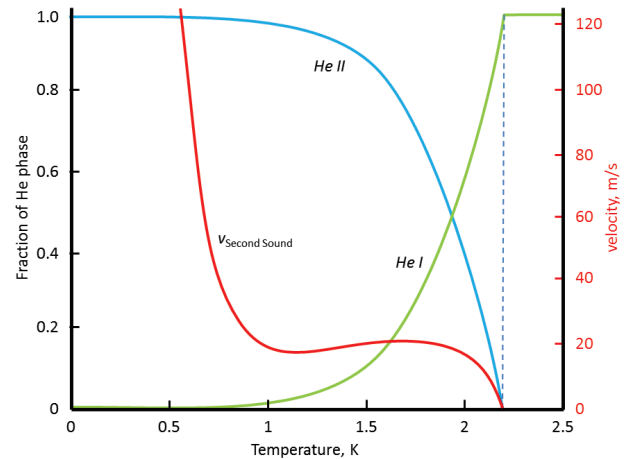


Figure 2: Helium phases and second sound velocity [1, 2].

This limitation significantly increases the complexity for measurements and algorithms for calculations.

EXPERIMENTAL SETUP

In the setup second sound oscillations are detected by oscillating superleak transducers (OST) [3, 4]. Within the OST the electrical capacity changes due to oscillation of the ratio of the fractions of helium phases. Typically second sound tests are performed at 1.8 K as the ratio of He I and He II phases is close to 1:1 and the capacitance change is maximal (see Fig. 2). The corresponding velocity of the second sound is 19.9 m/s [1].

While the OST is biased, its capacitance change leads to voltage changes on the measuring resistors. The voltage oscillations on this resistor can be easily measured after amplification (see Fig. 3).

For testing of dressed cavities a special Multi-OST sensor was developed. It consists of 6 OSTs placed in a single housing (see Fig. 4 for following details). Each OST consists of a copper anode of 7 mm diameter (2), which is biased with 120 V DC, and the porous membrane with golden layer (4), which serves as cathode. Anodes are isolated from the housing (1) by dielectric epoxy (3). Each OST has independent readout. A retractable mounting allows quick installation of the Multi-OST into the nozzle tank tube of a standard E-XFEL cavity with precise (ca. 1 mm) positioning accuracy (see Fig. 1).

The signal amplifier is in-house built and based on a simple operational amplifier circuit (see Fig. 3). Noise level demands require full cable shielding and the positioning of the ADC inside the amplifiers box. It is also necessary to stabilize the power buses for operational circuits, which

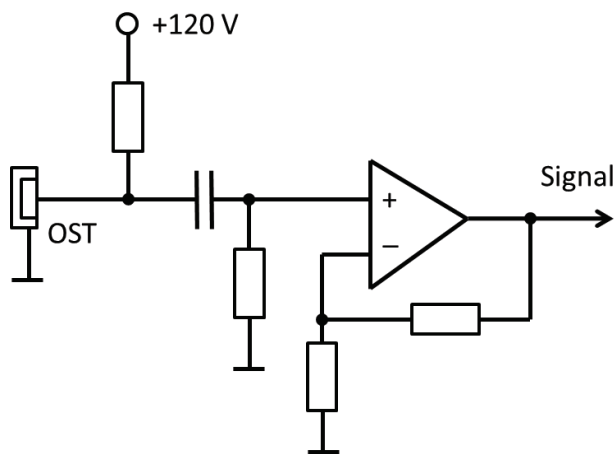


Figure 3: Amplifier circuit for OST signals.

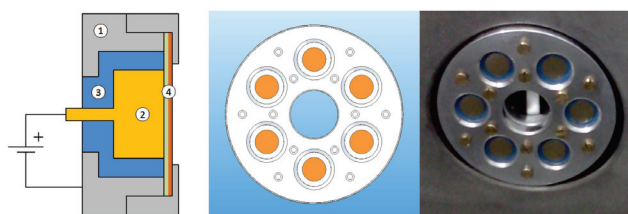


Figure 4: MultiOST sensor: schematic (left), common view (middle) and image of the sensor installed in the dummy helium vessel (right). 1 - grounded housing, 2 - anode, 3 - dielectric epoxy, 4 - porous membrane with gold layer.

allowed using of common electrical network. The signal to noise ratio (SNR) of acquired signals is about 32 dB. Signals are acquired with a rate of 30 ksps (see Fig. 5).

ALGORITHM

The key information of the measurement is the delay between the quench time detected from the RF signal (reflected or/and transmitted RF power) in the cavity measurement setup and the OST signal (detection time) (see Fig. 5). Using several OSTs with known second sound velocity the position of the quench origin can be calculated.

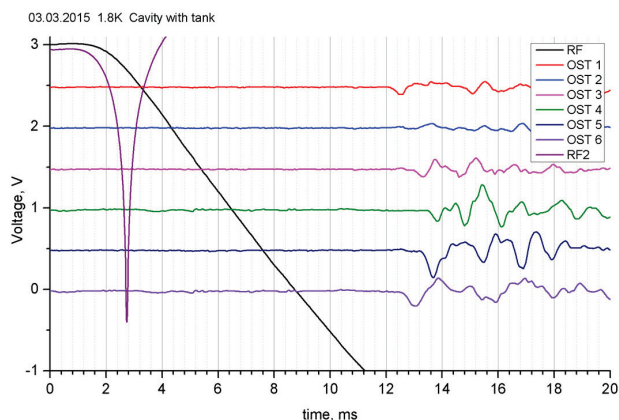


Figure 5: OST and RF signals taken during the vertical test.

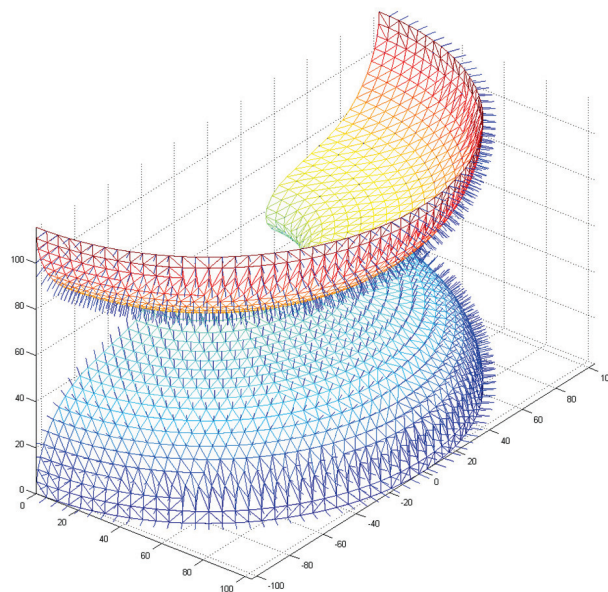


Figure 6: Dumbbell shape with normals and triangular mesh.

The facts that trilateration can be done only for OST in the direct line of sight of the quench and at least 3 signals are needed for quench localization increases the amount of OSTs placed around the cavity. Even a setup with 18 OSTs, as in use at DESY, does not ensure a proper localisation of the quench position. In that case information from OSTs which are not in the direct line of sight of the quench area is typically ignored. Using a simulation of the cavity geometry it is possible, by Hamilton's principle, to find the shortest path between any point of cavity surface and the known OST position without the assumption of a direct line of sight. To this end the quench position evaluation was done by a path-finding algorithm using full 3D cavity shape simulations (see Fig. 6).

The algorithm is based on some assumptions:

1. The front of the second sound wave will reach the OST by the shortest possible way (diffraction of second sound).
2. The velocity of second sound in helium is constant for the whole volume of cryostat at a given temperature.

The algorithm finds the shortest path between the OST and any point on the cavity surface even if it is not in the direct line of sight of the OST. In the common case, it is a combination of direct ray(s) in free space and one or several geodesics on the cavity surface. As only the shortest path is used there is no need to calculate any reflections. But some parameters, such as a finite membrane area of the OST, stiffening rings with holes etc. are accounted for.

Distance Map

Distance matrices - called distance maps - were calculated by the path-finding algorithm.

The distance map is a matrix of the shortest path s between a single OST and each point on the cavity surface. To parametrise the map a modified cylindrical coordinate system is used. The row of the distance map corresponds to axial coordinate z along the surface; the column corresponds to the angle coordinate ϕ of the surface point relative to the cavity axis. It allows the homogeneous coverage of the cavity surface.

Due to the axial symmetry of the cavity the distance $r_1' + a_2'$ from the OST to point Q_2' is equal to the distance $r_1 + a_2$ from the OST to the symmetric relative point Q_2 (see Fig. 7). This symmetry allows the calculation of the distance map only for half of the cavity surface and then mirroring it for the second half. Also due to the axial symmetry the changes of the angular OST position leads to a shift of cavity coordinates on the distance map for this OST.

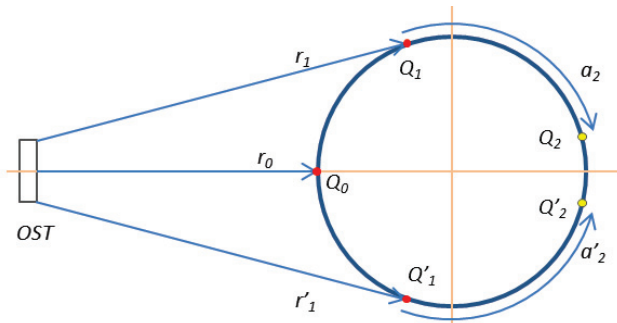


Figure 7: Axial symmetry of the cavity.

The calculation of such maps is computationally intensive depending on the desired accuracy. Since the Multi-OST position is well defined and all relative positions of Sub-OSTs are defined too, there is no need to calculate the cavity shape for each tested standard E-XFEL cavity. Pre-calculated distance maps are used during second sound tests for a fast evaluation of quench coordinates.

Quench Position Evaluation

The OST running time t_{OST} is defined as a delay between the RF-detected quench and the OST signal (see Fig. 5). For each OST the quench distance d_{OST} is calculated from the OST running time as proportional to the second sound velocity for given temperature v_{sound} [1].

$$d_{OST} = v_{sound} t_{OST} \quad (1)$$

The differences between value d and actual distance s from the surface point with coordinates z and ϕ to the OST is calculated for all OSTs for every point of the distance map. For every OST the deviation of distances for every point of the cavity is calculated:

$$RMSE_{z,\phi} = \sqrt{\frac{\sum_{i=1}^n (s_{z,\phi} - d_i)^2}{n}} \quad (2)$$

With $RMSE$ as root mean square deviation, and n is the number of OSTs used for calculations.

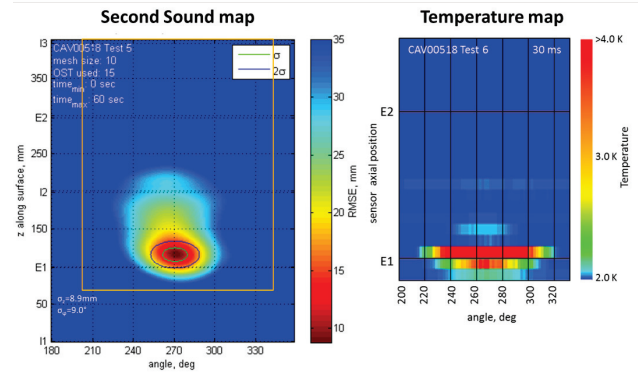


Figure 8: Quench map with T-map of the same area.

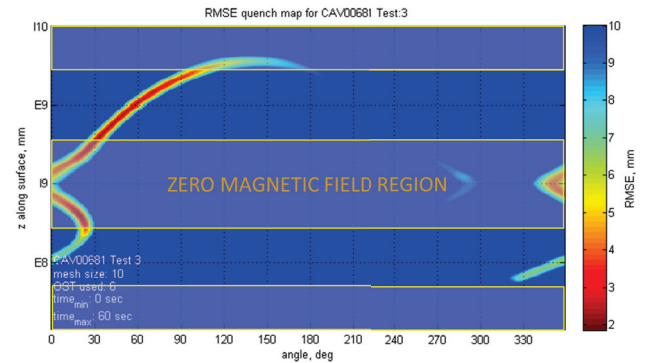


Figure 9: Part of the quench map of the dressed cavity.

The calculation of the RMSE for each point of the distance map yields a matrix of the same dimensions called quench map (see Fig. 9). This map shows probable positions of the quench source defined by the cavity geometry. The smaller the deviation the more likely is a surface point the quench origin.

This algorithm was verified by second sound tests of several naked cavities (without the helium vessel) with several single OSTs placed around and cross-checked by temperature mapping. In those tests the uncertainty σ_z was below 9 mm and σ_ϕ was around 9° (see Fig. 8).

RESULTS ON DRESSED CAVITY

One of the standard dressed E-XFEL cavity was tested with this Multi-OST and the algorithm. Part of the resulting quench map is shown in Fig. 9.

For TESLA-shape cavities the highest surface magnetic field is located close to the equator region and vanishes at the iris region. As it is seen in this example the area with the lowest deviations for each OST intersects only one equator (E9) at the angle between 45° and 65° . This area is the most probable source of a second sound wave.

During the optical inspection with the OBACHT tool a large defect was found on the electron beam welding seam inside the cell 9 at 50° (see Fig. 10).

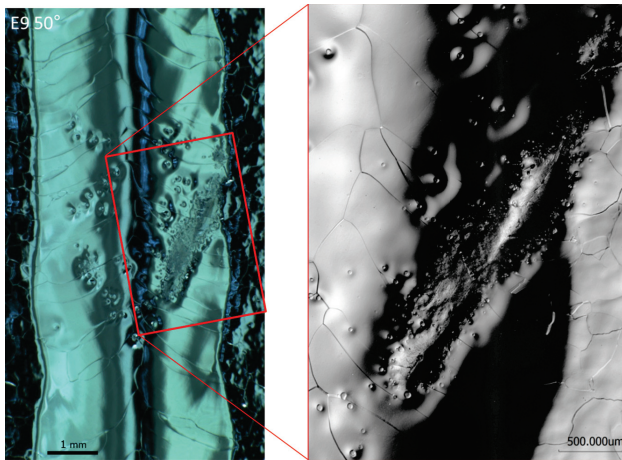


Figure 10: OBACHT image (left) and laser image (right) of the defect in equator 9.

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CONCLUSION

A new measurement system for second sound analysis has been developed and commissioned. It consists of a specially developed Multi-OST sensor with a mounting system, a redesigned amplifier, an universal code which allows for full 3D simulation of the cavity and testing software based on LabView. The numerical approach based on Hamiltons principle and the minimization of deviations was verified by tests of naked cavities using various setups of OSTs and cross-checked by temperature mapping.

This system allows second sound analysis of dressed cavities. It does not require any mode measurements, which can only detect the limiting cell, hence there is no need to dismount HOM antennas, a procedure requiring a clean room. A retracting mounting system allows precise positioning of the sensor. The installation/dismounting process takes less than 2 min including cables connection. This ready-to-use system could be routinely used as a part of the standard vertical test during the cavity production.

This approach can be adopted for the testing of non-elliptical SRF cavities.

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