A SIMPLE SECOND SOUND DETECTION TECHNIQUE FOR SRF CAVITIES

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Abstract

A simple technique based on an in-situ moveable germanium resistance thermometer is being built to measure the quench location in superconducting rf (SRF) cavities in superfluid liquid helium. SRF cavities are very often limited in operating field level by thermal instability manifesting as a transient "quench" of the electromagnetic field. The field energy is transferred into the superfluid helium bath as a heat pulse and may be detected as a wave of phonons at a thermometer. The germanium resistance thermometer technique was developed at Argonne three decades ago and used to measure time-of-flight of the second-sound to locate defects in split-ring resonators for the ATLAS SC linac at Argonne. The present goal is to extend and adapt the second-sound diagnostic technique in a simple, easy-to-use and cost effective way for use with cavities under development today. These include for example, single- and 9-cell 1.3 GHz SC cavities, as well as, reduced beta superconducting cavities such as half-wave and quarter-wave structures.

INTRODUCTION

A quench of the field in an SRF cavity results in a pulse of heat being introduced into the cooling helium bath. If the helium is superfluid (colder than 2.17K), the heat pulse is propagated as a wave of phonons - a pulse of so-called second-sound. Single-crystal germanium resistance thermometers (RTD's) have sufficient sensitivity and short enough response times to detect such waves. The technique provides positional information on the location of the quench and is complementary to carbon resistor arrays, commonly used to determine the spatial distribution of heating on the cavity rf surface.

BACKGROUND

The ANL split-ring resonators originally designed more than 30 years ago are still among the most complicated superconducting accelerating structure ever built with more than two dozen separate niobium parts joined together by 32 separate electron beam welds. Then, as now, beam welds and a variety of other material defects generally limit the performance of SRF cavities and a quick and accurate means of locating these defects is required.

Figure 1. shows second sound measurements performed in 1977 by Shepard et al.[1] for a pair of split-ring cavities. The upper traces are a measure of the cavity rf field showing the characteristic decay time of ~3 mS for a quench initiated by thermal-magnetic instability. The lower traces are the measured voltages across germanium

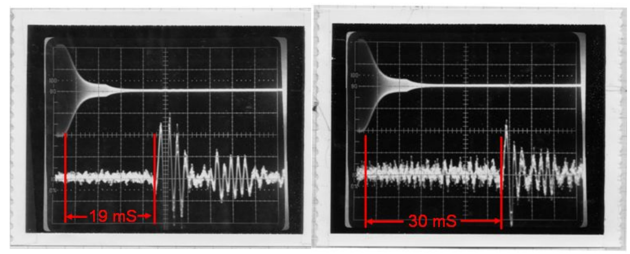

Figure 1: Second sound quench detection at ANL in 1977 measured separately for a pair of SC split-ring resonators.

RTD's showing the second sound pulse arriving at the sensors, 19 mS (left) and 30 mS (right) respectively, after breakdown. This technique was used extensively to locate quenches to within 1-2 cm in order to perform a local repair on the rf surface. Also, second sound detection was relatively simple since the split-ring loading arms (where quench was likely) are a quasi- 1-dimensional system and permit a straightforward interpretation of the measured signal.

The most practical experimental setup for quench detection is generally dependent on the 3-D cavity/cryostat geometry. Some cavities, including the 1.3 GHz single cell elliptical cavity, shown mounted on the lid on the new ANL 2 Kelvin test cryostat in Figure 2, lend themselves to detection with either a single or a small

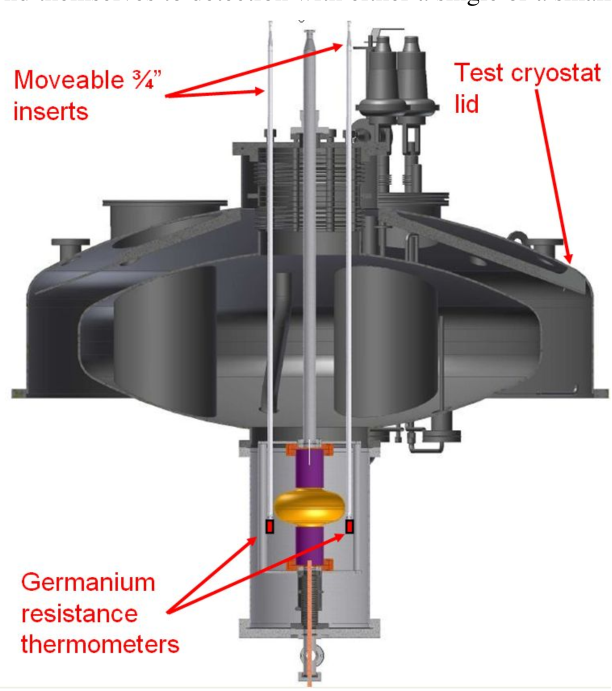

Figure 2: Second sound quench detection with movable sensors.

Figure 3: Commercial and ANL in-house germanium resistance thermometers (top) and 2nd sound testing in a 6” He dewar (bottom).

number of moveable detectors permanently attached to the cryostat rather than on the cavity. We have built and tested a moveable 3 meter long by 2 cm OD insert fabricated from thin walled stainless steel tube and a short section of G-10 for mounting the RTD’s. The model in Figure 2 shows two of these moveable inserts to be used to locate quench in a singe-cell cavity. Figure 3. shows one of the inserts undergoing tests in a 6” helium dewar. Positional information, both along the vertical axis and azimuthally should be obtainable on elliptical-cell cavities with only 2-3 sensors. A new 2 Kelvin test cryostat at ANL has many access ports at the top of the helium vessel

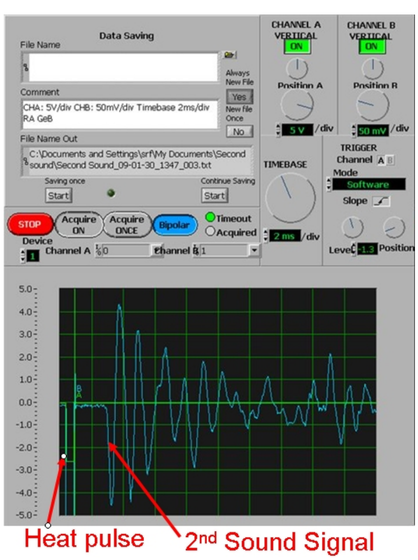

Figure 4: LabView data acquisition system for recording individual second sound pulses.

suitable to accommodate the inserts. The same system should be equally suitable for quench detection in 9-cell cavities with the addition of a longer cavity helium vessel.

THERMOMETER TESTING

In order to test the operation of two types of germanium RTD’s available to us today, a series of measurements have been performed. Figure 3. shows a germanium RTD from LakeShore, model GR-200A-500, (left) and a thermometer fabricated in house at ANL from a bare single crystal of germanium (right). The crystal inside the commercial device has been exposed by carefully removing the manufacturer’s cylindrical copper enclosure with a jewelers file. The device on the right was fabricated at ANL starting with a bare germanium crystal. A thin gold film was evaporated onto the ends of the crystal and copper leads were attached to the gold film by indium soldering.

Measurements were performed in a 6” helium dewar (Figure 3 – bottom) with germanium RTD’s mounted on the moveable insert. A pair of film resistors, at 1.5 cm and 8 cm from the thermometer, was mounted to the insert and used to simulate cavity breakdown by generating a fast, ~2 mS, heat pulse into 1.9 Kelvin liquid helium. An example of an individual heat pulse and second sound signal is shown in Figure 4. The measured response time of the RTD’s is better than 0.5 mS, corresponding spatial resolution is 1 cm or better. Previous tests with SRF cavities indicate a spatial resolution somewhat (2-3X) lower [1]. This is expected due to the finite size of the normal region (several cm) into which the cavity rf energy is dissipated. A detailed model analysis of this effect is in preparation [2].

Detector Sensitivity

Efforts have been made to optimize the sensitivity of the sensors in the test setup. Measurements were performed, using a standard 4-wire technique. A battery box and a variable potentiometer were used to set the RTD bias current. Generally, the RTD response to a second sound pulse increases as the bias current is raised from zero. At some value the self-heating (I^2R) losses become substantial raising the temperature of the sensor and lowering sensitivity (1/R x dR/dT). Here, the resistance of the LakeShore RTD’s at T=1.9 K and with small bias currents of 20µA or less was measured to be 4.8 kΩ, in fair agreement with LakeShore specifications. Measureable self heating was first observed with I_{Bias}~50µA, however, the best overall signal-to-noise ratio was found for relatively large bias currents in the range of 500µA - 1mA as for the signal shown in Figure 4.

FUTURE PLANS

Second sound testing with the system described here is planned initially for an ANL coaxial half-wave SRF cavity. This geometry is highly favorable since it should permit the location of a quench using a single movable germanium RTD inside the central conductor. The half-wave test will be followed by testing with a single-cell elliptical cavity to be provided through the ANL/FNAL collaboration on SRF cavities.

CONCLUSION

A simple and convenient technique based on an in-situ moveable germanium resistance thermometer has been tested with fast heat pulses in superfluid liquid helium. The system may be used to detect quenches in a variety of cavity geometries with only a few sensors and does not require disassembly or reassembly for each cavity test. Upcoming tests using the moveable germanium thermometers are planned for both TEM and elliptical cell cavities using a new ANL 2 Kelvin test cryostat.

ACKNOWLEDGEMENTS

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REFERENCES

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