Identification of Quench Location in Superconducting Radio-frequency Cavities

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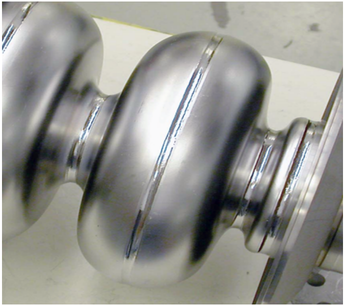
Superconducting Radio-frequency Cavity (SRF)

- Accelerating structures for next generation of particle accelerators
- Made up of pure Niobium (Nb) , 9 cell
- Very high quality (Q) factor (2.7 x 10^{10}) compared to that of normal -conducting cavities ($10^4 - 10^5$)

- Surface resistance- 10nΩ at 2K and frequency 1.3 GHz
- Rf magnetic field at inner surface should be below the super-heating field (200-240 mT) which means maximum accelerating field of 50-60 MV/m.

Quench on a SRF cavity

- While operating at an accelerating gradient of 35 MV/m even a small imperfection of the cavity surface matters
- Low thermal conductivity of Niobium ($125 Wm^{-1}K^{-1}$ at 4.2K)
- Heat gets accumulated at one spot of the cavity and leads to a quench.



- The quench is defined as a loss of a superconducting state. Therefore, it is NOT GOOD when we want to run our system at temperature of about 2K to maintain superconductivity.

Resistance Thermal Detectors (RTDs)

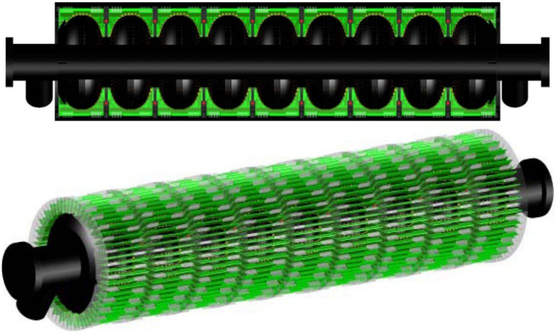
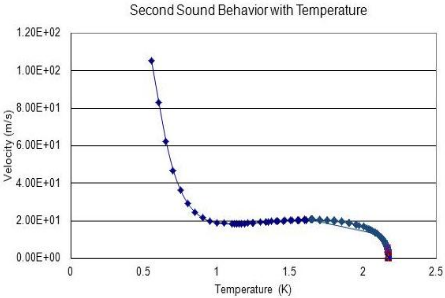


Figure: The arrangement of RTDs around a 9 cell cavity for the quench location. Image courtesy: Ninoshka Fernandes, Lee Teng Intern 2009

Second Sound

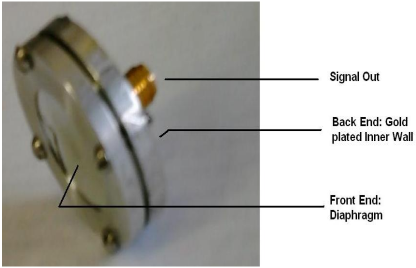
- Phenomenon in which heat is transferred as a wave rather than by diffusion.
- Only observed in superfluid i.e. in this case, for Helium at the temperature below 2.17K (He II)



- This wave is analogous to sound wave, and can also be heard through microphone!
- In a cavity test, we can observe second sound generated at the quench location.

Oscillating Superleak Second Sound Transducers (OSTs)

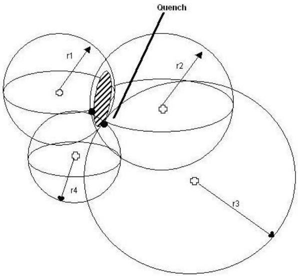
- Cylindrical in shape. Diaphragm at one end and a bronze coated wall connected to SMA connector at the other.
- Porous diaphragm allows only superfluid part of the He II to transmit.
- Diaphragm oscillates as the second sound arrives and causes changes in the biased voltage.



- Can be modeled with acoustic circuit and the acoustic compliance of the second sound and transducer can be treated as capacitor.

Trilateration

- Suppose the location of the OSTs are (x_i, y_i, z_i), where i=1,2,3,4 for four OSTs and quench be located at (x, y, z). Then, the distance between OST and quench would be: $(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2 = r_i^2$
  Then,



$$M = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) & 2(z_2 - z_1) & s \\ 2(x_3 - x_1) & 2(y_3 - y_1) & 2(z_3 - z_1) & t \\ 2(x_4 - x_1) & 2(y_4 - y_1) & 2(z_4 - z_1) & u \end{bmatrix}$$

Trilateration

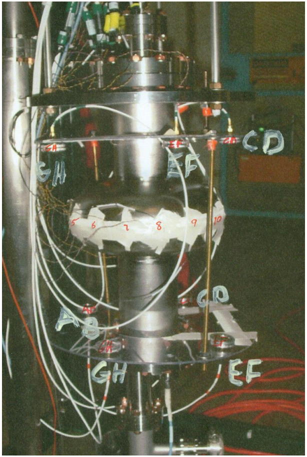
where, $$\begin{aligned} s &= x_2^2 - x_1^2 + y_2^2 - y_1^2 + z_2^2 - z_1^2 - r_2^2 + r_1^2 \\ t &= x_3^2 - x_1^2 + y_3^2 - y_1^2 + z_3^2 - z_1^2 - r_3^2 + r_1^2 \\ u &= x_4^2 - x_1^2 + y_4^2 - y_1^2 + z_4^2 - z_1^2 - r_4^2 + r_1^2 \end{aligned}$$

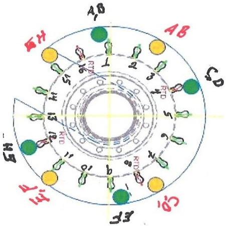
- Now, we can obtain the reduced row echelon matrix of the above, augmented matrix to achieve the form:

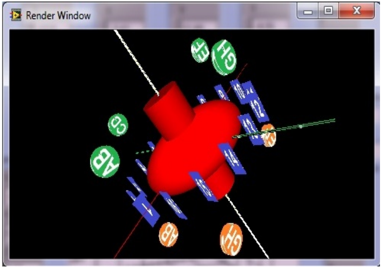
$$M = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \end{bmatrix}$$

where, x = a, y = b and z = c - defines the position of the quench.

Experimental Setup

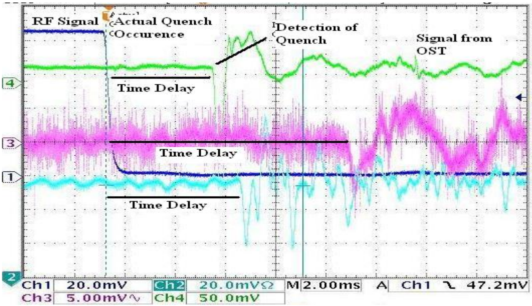






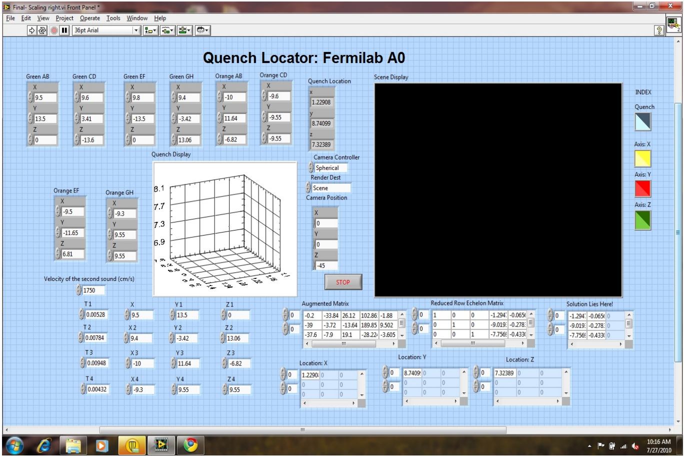
...back to Trilateration

- Now, we can "see" the quench from the eyes of the transducers
- Sudden drop in RF signal implies the occurrence of quench.

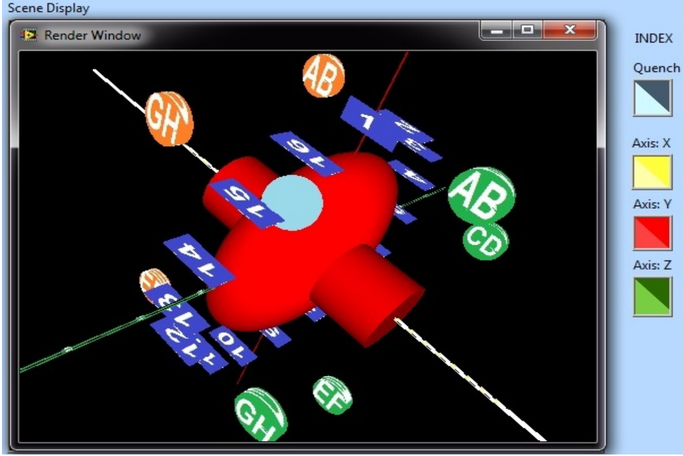


- Time delays between the occurrence of the quench and arrival of second sound at each transducer can be measured.
- Since the velocity is known based on the temperature, the distances between OSTs and quench can be calculated. Then, position is calculated by using Trilateration.

Software Development

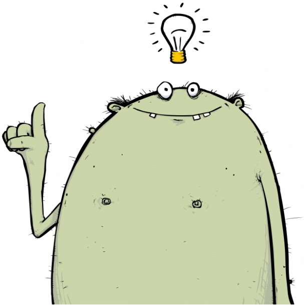


Software Development



Conclusion

- Based on Trilateration, the quench can be located quite precisely - on the order of millimeters.
- A program based on LabVIEW was developed to:
  - Perform speedy calculations of the quench location
  - Provide 3D visual display for the users.



- With computationally powerful programs like MatLab or LabVIEW Mathscript or Mathematica, one might be able to find the quench based on the signals from as few as two transducers and cavity geometry.

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Your Turn!