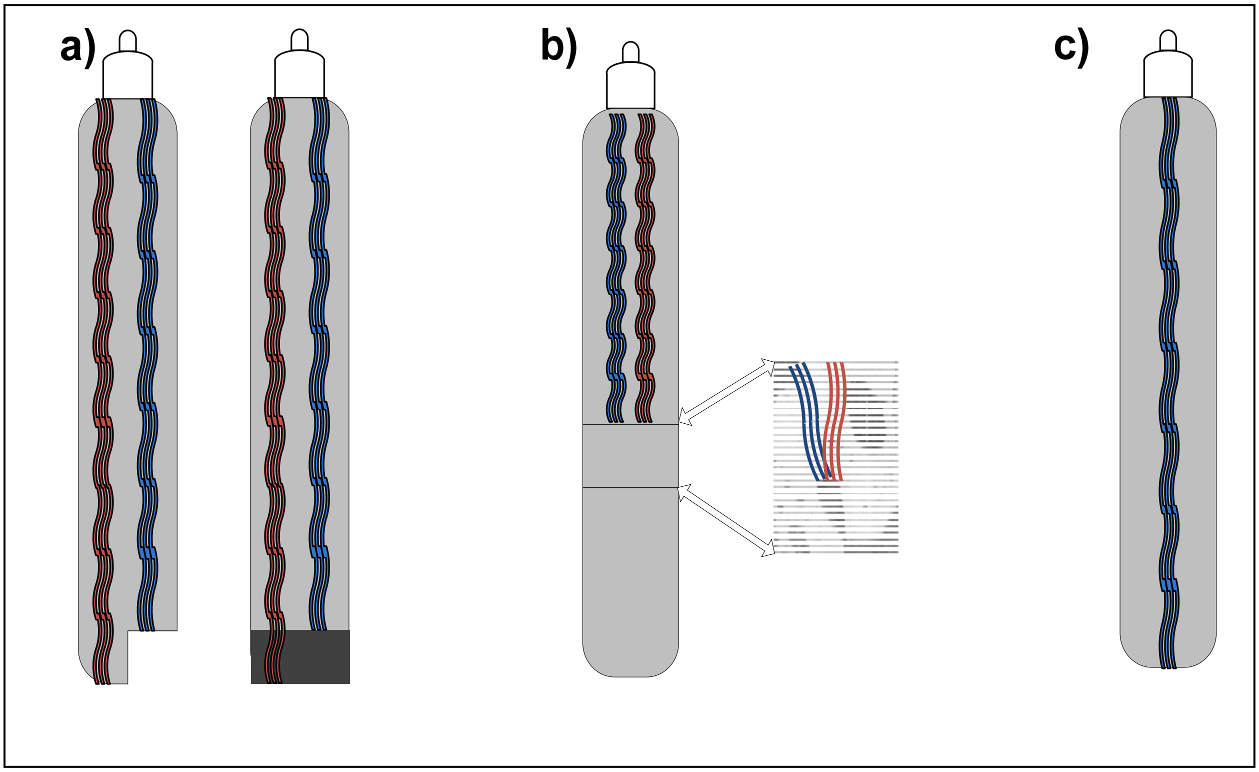
Localization Methods in Ultrasonic Thermometry

Ultrasonic Thermometry has been used for more than 50 years to estimate the average temperature in solids, liquids and gases. With recent advances in instrumentation, sensors, and signal processing, it is both technically feasible and economically attractive to use ultrasound to non-intrusively measure local temperature with objects using ultrasonic echo data.

Three different methods are illustrated in Figure 1. Figure 1a demonstrates the use of structural echoes from interfaces within a component. The echoes can arise from a gage change, a layer, or even a defect such as a crack. Figure 1b shows the situation where the grain structure itself can be used to give rise to internal ultrasonic backscatter and thus provide a vehicle for temperature localization. In Figure 1c the reflection from a single interface is combined with thermal models and inversion methods to determine the temperature and heat flux at the reflecting surface.



Sketch showing concept for three different temperature localization schemes used in ultrasonic thermometry: a) Structural echoes; b) Backscatter analysis; c) Inversion methods.

Structural Echoes

The most direct way to use ultrasound to remotely measure temperature is to exploit the characteristics of structural echoes. Figure 1 shows the results of a temperature measure at the tip of a copper bar using an ultrasonic sensor attached 250 mm from the measurement point. This bar has a 6mm step gauge change which gives rise to a pair of echoes; one from the step and one from the end of the bar as shown in Figure 1b. The shaded area in Figure 1a shows the heated zone of the bar tip. Figure 1c shows a plot of the time history of the fractional variation in the time-of-flight separation between the echoes compared with thermocouple temperature measured at both the end (TC1) and step (TC2) region of the bar. By monitoring the change in separation of these two echoes as the sample is cooled from 400^{o}C the local temperature of the step region can be measured using a sensor attached 250 millimeters from the heated zone. In this case the response time of the measurement is limited by the thermal mass of the step.

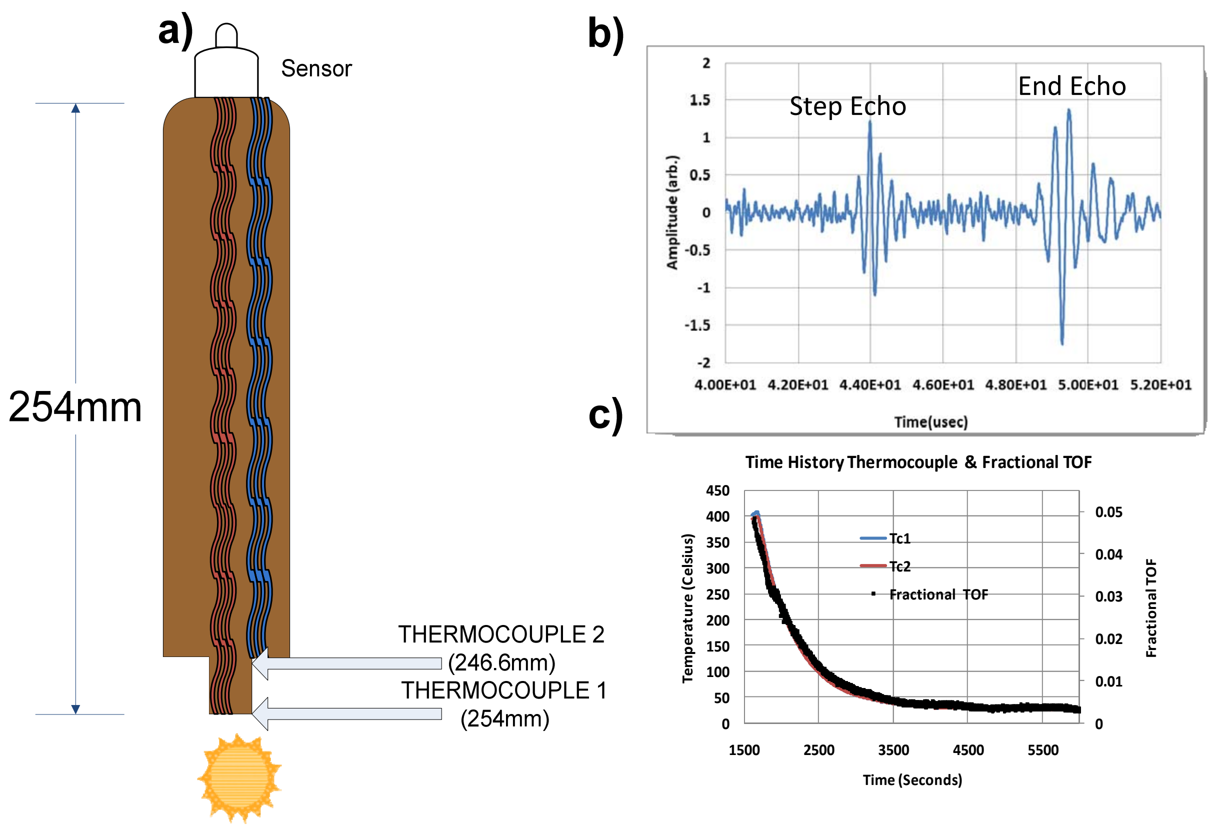


Figure 1 a) Configuration for structural echo measurement in copper bar; b) echo pair from the tip of the bar; c) comparison of ultrasonic time-of-flight and thermocouple measurements.

Temperature from Backscatter

In situations where no structural echoes are available for localization, it may be possible to derive estimates of local temperature using backscatter echoes from the material grain boundary scattering. Figure 3 illustrates an example of monitoring internal temperature variations by utilizing the diffuse backscatter echoes in copper. A technique similar to this has been used successfully in clinical medicine to measure internal temperature to control hyperthermal treatment of tumors. Figure 3a shows the testing configuration with sensor attached to the far end of the rod. In Figure 3b complex ultrasonic backscatter echoes from a 75mm long segment of the bar are shown divided into 15 distinct regions. Region 1 contains echoes originating 142 mm from the sensor while region 15 has echoes originating 206 mm from the sensor location. Figure 3c is a 3 dimensional plot showing the time-of-flight, clocktime, and echo depth index as the sample is non-uniformly heated. The temperature at 206 mm reaches a temperature of 200^{o}C and then cooled to back to ambient temperature. The depth index corresponds to the 75 mm region shown in Figure 3b. The maximum temperature gradient of the 75 mm is 50^{o}C.

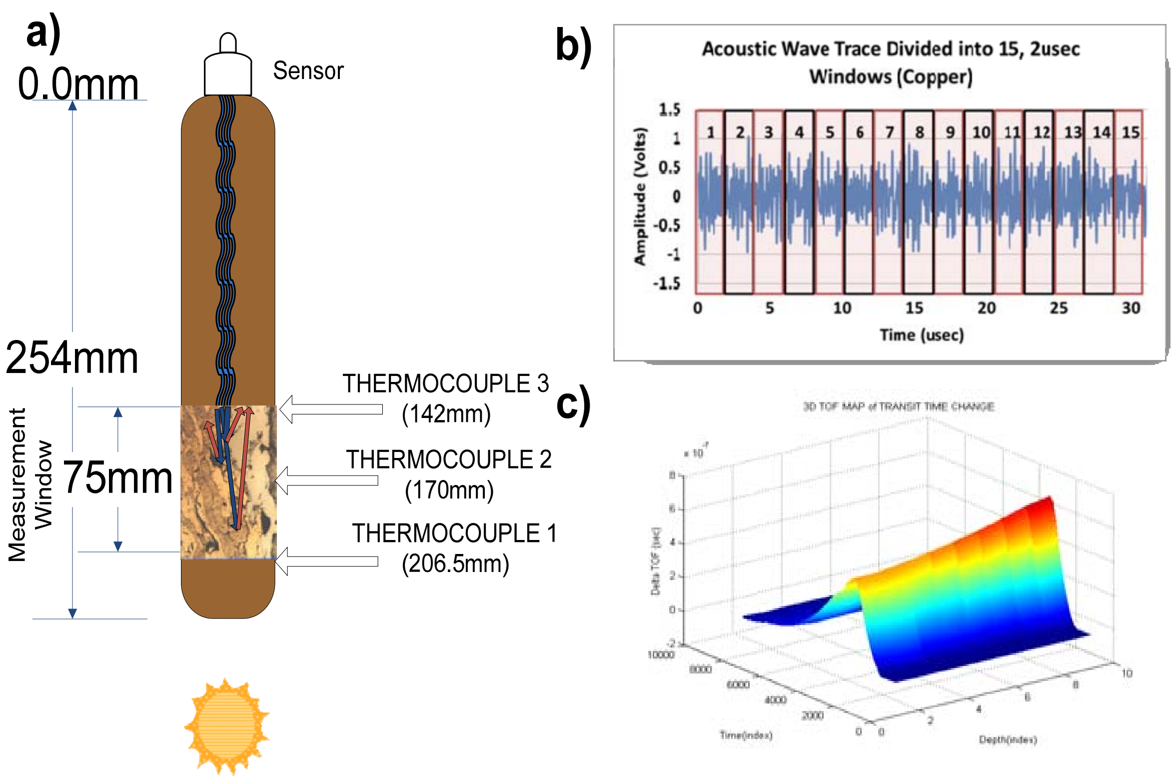


Figure 3 a) Measurement configuration for backscatter time-of-flight analysis on copper; b) backscatter echoes from 75 mm region indicated in 3a; c) time-of-flight, clocktime, depth plot as sample is heated non-uniformly to produce a maximum gradient of 50^{o}C over the 75 mm backscatter region.