4.15 Ultrasonic and Sonic Thermometers


Applications: Temperature measurement inside nuclear reactors, cement kilns, boilers, and in furnaces. Suited for harsh and abrasive environments.

Types: Piezoelectric and magnetostrictive. Detects average temperature.

Temperature Ranges: 32 to 3500°F (0 to 1927°C) for boiler/furnace units, higher with quartz probes

Inaccuracy: 1.5%, does not require calibration

Measurement Time: 15 s/path

Number of Paths: 1 or 2

Required Air Supply: 80 to 120 PSIG (5.5 to 8.3 bars)

Waveguide: 316 SS with 3 in. 150# pipe flange

Cost: $5,000 to $10,000 or more

Partial List of Suppliers: Scientific Engineering Instruments (www.sciengr.com)

OPERATING PRINCIPLE

The speed of sound in a gas is proportional to its temperature. This relationship between sound velocity and temperature has been known for nearly 100 years, but until recently it has been little used. Temperature dependence of velocity in an ideal gas is expressed as

$$v^2 = \frac{\gamma RT}{M_w} \quad 4.15(1)$$

where \(v\) is sound velocity, \(\gamma\) is the ratio of specific heats, \(R\) is the gas constant per mole, \(M_w\) is the molecular weight, and \(T\) is the absolute temperature.

A method of temperature measurement in a plasma jet involves the use two quartz probes set a fixed distance apart. The sound velocity is determined by circuitry for the continuous measurement of the ultrasonic wave transit time (see Figure 4.15a).

As temperature is detected by the measurement of time, calibration is not required and this linear sensor is well suited to harsh and abrasive environments. Because the gas itself is the thermometer element, errors such as leakage are absent and fast changes can be followed. Disadvantages include high cost, nonideal gas behavior, pressure correction, accurate determination of \(\gamma\) and the inability to make point measurements.

Ranges and Applications

Acoustical temperature sensors can theoretically measure temperature from the cryogenic range to plasma levels (20,000°C, or 36,000°F). The accuracy can approach that of a primary
Temperature Measurement

Temperature measurements can be made not only in gases, but also in liquids or solids. The relationship between sound velocity and temperature for various materials is shown in Figure 4.15b.

The acoustic velocity can be detected by immersing a rod or wire into the fluid or by using the medium itself as an acoustic conductor. The sensor rod can measure the temperature at a point or, by means of a series of constrictions or indents, can profile or average the temperature within the medium. This is done by measuring the time lags of the sound waves as they are reflected from the consecutive indents (see Figure 4.15c).

When the medium is used as the conductor of the ultrasonic pulse, the transducer can also be located within the vessel, but is usually placed on its external shell. This latter configuration is useful when measuring the temperature of solids or extremely hot or corrosive materials such as molten sodium. The acoustic pulse can be generated by a piezoelectric crystal cut to resonate at a frequency ranging from 0.5 to 3 MHz or by means of magnetostrictive materials.

The thin wire sensor (Figure 4.15c) is installed like a thermocouple (TC). A lead-in wire carries the pulse to the thin wire made of a material suitable for the process medium and its temperature range. Reflection from the beginning and the end of the thin wire provides the time lapse information for temperature determination. The selection of materials is more flexible than for TCs as only one material is involved.

Boiler/Furnace Applications

An acoustic sound source and a sound receiver can be located on the outside of opposing walls of a boiler, cement kiln, or furnace. Such noninvasive applications employ a transmitting transducer to send acoustic energy through the process medium. Receiving transducers detect the energy, and time delay is measured to determine the velocity of sound and therefore the temperature of the process. A nonintrusive, dual-path ultrasonic thermometer employing pneumatically generated sound waves is shown in Figure 4.15d. It does not require calibration; measures average temperature across two paths; has no moving parts other than the air supply valve; is linear; and can be provided with data display, logging, setup, and diagnostics either locally on a personal computer or remotely, using a modem connection.
Ultrasonic thermometry can be used at temperature extremes, in high electrical fields, or when the medium being measured is inaccessible. It is also useful for averaging the temperature of bulk materials or for profiling furnace temperatures. Other applications are tabulated in Table 4.15e.

CONCLUSIONS

Temperature measurement is a fast-changing technology. Today, smart temperature transmitters can be directly connected through data highways to any distributed control system. These transmitters also improve accuracy, because they eliminate the need for analog-to-digital conversion and are able to self-calibrate their spans, self-diagnose their sensor’s integrity and automatically make selections from among their multiple sensors in order to provide automatic replacement or to match the prevailing temperature of the process.

Intelligent transmitters (as discussed in more detail in Sections 4.1, 4.10, and 4.13) reduce measurement error and increase measurement rangeability. Sonic and ultrasonic thermometers have a unique role for high temperature applications where the interest is in detecting the average temperature in harsh and abrasive process environments.

References


Bibliography


### Table 4.15e

<table>
<thead>
<tr>
<th>Measured Object</th>
<th>Temperature (°C)</th>
<th>Sensor or Medium</th>
<th>Sound Conductor</th>
<th>Transducer</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>1500–15,000</td>
<td>N₂</td>
<td>Quartz</td>
<td>Piezoelectric</td>
<td>One period 1 MHz</td>
</tr>
<tr>
<td>Liquid</td>
<td>1000</td>
<td>Molten Na</td>
<td>Stainless steel</td>
<td>Piezoelectric</td>
<td>One period or period series 3–10 MHz</td>
</tr>
<tr>
<td>Solids with holes</td>
<td>3000</td>
<td>Re-wire</td>
<td>Tungsten</td>
<td>Magnetostriuctive</td>
<td>Period series 0.1 MHz</td>
</tr>
<tr>
<td>Solids without holes</td>
<td>1500</td>
<td>Steel wire</td>
<td>Steel</td>
<td>Piezoelectric</td>
<td>Period series 1 MHz</td>
</tr>
</tbody>
</table>
Kleppe, J.A., “The Reduction of NOx and NH3 ‘SLIP’ in Waste-To-Energy Boilers Using Acoustic Pyrometry,” Power Gen Americas ‘93, Dallas, TX, November 1993, p. 421. This publication is also available on our literature page.

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