4.5 Fiber-Optic Thermometers


Types of Sensors: Light-pipe, blackbody, dual-wavelength, crystal, gap, and fluoroptic

System Components: Fiber-optic assembly, infrared detector, and electronic console

Applications: Temperature measurement of hard-to-reach objects. Used in calendering, crystal growing, engine heads (spark plugs), glass fore-hearths, induction heating, kiln hot spots, medical hyperthermia, microwave packaging, polymer melting, printer operations, reactive-ion etching, transformer windings, vacuum processing, web drying, and welding.

Wavelengths Used: 0.7 to 8 \( \mu \text{m} \) for inexpensive total radiation detectors, 2.2 to 3.8 \( \mu \text{m} \) for penetrating intervening atmosphere, 2.2 \( \mu \text{m} \) for metals, 4.5 \( \mu \text{m} \) for flames, under 8 \( \mu \text{m} \) for glass

Field of View: The ratio of target distance to target size can range from 3:1 to 900:1.

Fiber Size and Lengths: Single fiber is 0.5 mm in diameter, 4-fiber array is 0.9 mm in diameter. The number of fibers per cable ranges from 30 to 400; their lengths range from 10 to 300 ft (3 to 100 m).

Temperature Ranges: Can detect from 212°F (100°C), but the typical range is from 500 to 5500°F (260 to 3600°C); some units go up to 6500°F (3600°C). Allowable ambient temperature range is from –76 to 535°F (–60 to 315°C). –50°F to 6500°F (–46 to 3600°C) for Spot instruments; 100 to 3500°F (37 to 2000°C) for Line Scanners; 0 to 3500°F (0 to 2000°C) for Thermal Imagers.

Transmission Range: 0.7 to 8 \( \mu \text{m} \)

Spectral Response: 2.0 to 2.4 \( \mu \text{m} \)

Response Time: 0.3 s or better

Total Acceptance Angle: 22 to 60°

Stability: Drift is under 0.5°F (0.3°C) over period of 10 days.

Inaccuracy: From as low as 0.2°F (0.1°C) to 1% full scale.

Costs: Transmitters are in the $2500 to $4500 range. A 0.1°F resolution microprocessor-based unit with PID algorithm included is about $6000; the same unit with 2, 4, 6, or 8 channels is about $15,000, thermal imaging systems up to $60,000.

Partial List of Suppliers: Accufiber Div. of Luxtron Corp. (www.luxtron.com)
Barber-Colman Industrial Instruments (www.barber-colman.com)
FLIR (www.flir.com)
Indigo Systems (www.indigosystems.com)
Hart Scientific (www.hartscientific.com)
Ircon (www.ircon.com)
Land Instruments (www.landinst.com)
MetriCor Inc. (www.metricorinc.com)
Mikron Instruments Co. (www.mikroninst.com)
Infrared (IR) and radiation pyrometers are discussed in Section 4.9. This section will concentrate on combining those principles with the use of optical fibers, which provide the ability to look at the temperature of small objects or to look around opaque objects.

Noncontact thermometry has many advantages, particularly in regard to measuring temperatures of objects that are extremely hot or corrosive, are moving or fragile, are in strong electromagnetic (radio frequency [RF], microwave, or direct current magnetic) fields, or are subject to measurement error due to heat loss by conduction. Until the glass-fiber optic cable became available, noncontact thermometry required line-of-sight vision between the sensor and the target object. The elimination of this restriction makes it possible for the fiber-optic thermometer to solve many difficult measuring problems.

Optical fiber thermometry (OFT) depends on total internal reflection within a thin fiber element. Absorption of IR energy by glass fibers has limited the low end of the range to 660°F (350°C) (see Figure 4.5a). Developments in telecommunications and glass research now promise to facilitate lower temperature measurements using alternative spectral bands (see Table 4.5b).

Some laboratory-standard fiber-optic instruments offer even greater accuracy than a type S thermocouple—±0.01% at 1832°F (1000°C) with a resolution of 0.01°C.

**THERMOMETER DESIGN**

Fiber-optic measurement systems consist of three elements: the fiber-optic assembly, an IR detector, and an electric console. A single fiber or bundle of several fibers gather IR radiation from the target, transmit to the detector, and convert the radiation to a voltage suitable to the required function.

Fibers are sensitive only to the IR portion of the spectrum and filter out other forms of radiation; they are not activated by flames and fumes. Even though IR radiation becomes detectable at about 140°F (60°C), it is best to use it at temperatures over 212°F (100°C) in any monitoring application.

Fibers, whether single or in bundles, are always enclosed in metal or ceramic sheaths for protection. A unique characteristic of the special glass fibers is the ability to bend light and to transmit it for distances up to 30 ft (9.1 m) without distortion or loss of definition.

Perhaps the one outstanding feature of fiber-optic systems is the ability of the fibers to withstand and function in hostile environments, including intense heat. Fibers maintain resolution exceeding one degree change at temperatures over 2000°F (1100°C). At extreme high temperatures and under

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**Omega/Vanzetti** ([www.vanzetti.com](http://www.vanzetti.com))

**Raytek** ([www.raytek.com](http://www.raytek.com))

**Square D, Infrared Measurement Div.** ([www.squared.com](http://www.squared.com))

**Technology Dynamics Inc.** ([www.technologydynamicsinc.com](http://www.technologydynamicsinc.com))

**Wahl** ([www.palmerinstruments.com/wahl/wahl.html](http://www.palmerinstruments.com/wahl/wahl.html))

**Williamson Corp.** ([www.williamsonir.com](http://www.williamsonir.com))

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![FIG. 4.5a](https://example.com/figure4.5a)

*The infrared transmission of glass fibers designed for high-temperature applications varies according to cable length. The sensors used for this purpose are filtered in the 0.8 µm region.*

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**TABLE 4.5b**

*Infrared Fiber-Optic Cable Comparative Specifications*

<table>
<thead>
<tr>
<th></th>
<th>Glass</th>
<th>Quartz</th>
<th>IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber diameter</td>
<td>0.002 in.</td>
<td>0.008 in.</td>
<td>0.008 in.</td>
</tr>
<tr>
<td>Fibers/cable</td>
<td>200–400 fibers/bundle</td>
<td>50 fibers/bundle</td>
<td>30 fibers/bundle</td>
</tr>
<tr>
<td>Cable diameter</td>
<td>0.063 in.</td>
<td>0.063 in.</td>
<td>0.063 in.</td>
</tr>
<tr>
<td>Transmission range</td>
<td>0.5–1.4 µm</td>
<td>0.7–2.4 µm</td>
<td>0.5–4.5 µm</td>
</tr>
<tr>
<td>Ambient limits</td>
<td>500°F</td>
<td>500°F</td>
<td>300°F</td>
</tr>
<tr>
<td>Total acceptance angle</td>
<td>68°</td>
<td>50°</td>
<td>22°</td>
</tr>
<tr>
<td>Flexibility rating</td>
<td>Excellent</td>
<td>Good</td>
<td>Limited</td>
</tr>
</tbody>
</table>
other severe conditions, the fibers are protected with air or inert gas purging or by water cooling.

The advantages of using fiber optics in noncontact temperature measurement application include their inertness, relatively rugged design, small size, and ability to look around opaque objects (Figure 4.5c). With the addition of a telescopic lens system, the same fiber-optic assembly can be made to monitor different target areas at various focal distances.

Radiation proportional to temperature is conducted along an optical fiber to a sensor connected to a measuring instrument. Variations on this basic principle make it possible to adapt this design to a variety of applications.

As with any optical instrument, a fiber-optic thermometer depends on observations of brightness or on total radiation. The measurement technique most often used is characterized by the distribution of energy by wavelength and field of view.

A number of factors affect the choice of wavelength. For example, general-purpose instruments use a wide energy band (8 to 20 µm). Inexpensive instruments cover 0.7 to 8 µm in order to include most of the total energy radiated by the hot object. For penetration of intervening atmosphere, shorter wavelengths of 2.2 to 3.8 µm are preferred. For metals (which have a high reflectance), the narrow band around 2.2 µm reduces the effect of emissivity variations. (For definitions of terms such as emissivity, see Section 4.9.)

Glass is more transparent at the shorter wavelengths (e.g., 0.8 µm). Reflection becomes critical above 8 µm, so the shorter wavelengths are used for molten glass temperature measurement. Flames (preferably clean) can best be measured at a wavelength of 4.5 µm.

Field of view is the other significant parameter characterizing optical measuring instruments. This is described in terms of ratio of the target distance to the target size, and ranges from 900:1 to 3:1. A single wavelength instrument measures the average temperature of the body filling its field of view. A dual-wavelength instrument measures the hottest part of the target within its field of view.

The available variations in fiber-optic probe sensor designs are shown in Figure 4.5d. The fiber-optic sensors fall into four categories: light-pipe, blackbody, dual-wavelength, and gap types.

The light-pipe design transmits the radiation from the target to the detector through an open tip, as shown in Figure 4.5e. The blackbody-type unit radiates heat from a cup of material, such as a thin coat of precious metal, surrounding the tip.
A sapphire optical rod is coated at the tip with a thin film of iridium or platinum and aluminum oxide. At elevated temperatures, the tip emits a band of wavelengths that are transmitted to a detector for measurement (Patent No. 4,576,486). A schematic of the complete system is shown in Figure 4.5f.

In the dual-wavelength optical pyrometer sensor, the radiation is focused through a lens onto the optical fiber link from a distance of up to 16 ft (see Figure 4.5g).

In another design, light of a fixed wavelength spectrum is transmitted from the instrument through the optical fiber to the sensor. Here the light is converted and returned as a different wavelength spectrum, the value of which depends on the temperature of the sensor. The wavelength of the returned light is scanned and presented as a temperature reading on the instrument display or output to one of the optional interfaces.

The Fabry-Perot thermometer uses a temperature-sensitive spacer that varies a gap width, establishing a series of spectral bands by means of optical interference (Figure 4.5h). Because it is entirely optical from the measurement end of the fiber to the detector, it can be made very small. The measuring range is 35 to 55°C with a resolution of 0.1°C. The detector can be a pyroelectric detector amplified by an FET preamplifier.

The fluoroptic sensor measures the decay time of a fluorescent material (magnesium fluorogermanate), which, after being energized by a short-wavelength light pulse, varies proportionally with temperature. The phosphors can be compressed into intimate contact with a surface to measure with little conduction loss (Figure 4.5i).

In Figure 4.5j, the fluorescent signal decay characteristics of the fluoroptic sensor are shown on the top, and the basic calibration curve of the phosphor sensor is shown on the bottom.

CONCLUSIONS

The advantages of OFT pyrometry include: the small size of the sensor, which does not require line-of-sight observation of the object and can be furnished with blackbody fibers. OFTs are not affected by RF, microwave, or electromagnetic fields or by shock and vibration; their range is wide and response fast, and they can average or provide temperature profiles through noninvasive remote measurements of temperatures of solid objects or immersed in liquids.

The main disadvantage of OFT pyrometry is the high unit cost of this measurement. The unit cost can be reduced through multiplexing, so that several OFT sensors are connected (through a multiplexer) to a common set of electronics.

Fiber-optic thermometers offer many options resulting in application to a wide range of industrial temperature measurements. A principal advantage is electrical and, sometimes, even physical isolation from the target. The glass or quartz fibers that transmit the temperature signal to a detector can be an integral part of the measurement, reducing lag and conduction error. This is true in the case of the blackbody.
Temperature Measurement

When selecting a fiber-optic thermometer for a given application, it is necessary to review all types of fiber-optic instruments for wavelength and field of view in order to optimize performance.

References


Bibliography


