Non-Contact Temperature Measurement

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VOLUME

1
Because of normal variations in the properties of materials used to construct radiation temperature sensors, new instruments must be individually calibrated in order to achieve even moderate levels of accuracy. Initial calibration is likely to be performed by the sensor manufacturer, but periodic recalibration—in-house or by a third-party laboratory or the original manufacturer—is necessary if any but the most qualitative measurements are expected.

The ongoing accuracy of a non-contact temperature sensor will depend on the means by which the calibration is performed, how frequently it is recalibrated, as well as the drift rate of the overall system. Ensuring the absolute accuracy of non-contact temperature measurement devices is more difficult than with most direct contacting devices, such as thermocouples and resistance temperature detectors (RTDs). Limiting the absolute accuracy to 1% is difficult; even in the most sophisticated set-ups, better than 0.1% accuracy is seldom achieved. This arises, in part, from the difficulty in accurately determining the emissivity of real bodies. Repeatability or reproducibility is, however, more readily achievable than absolute accuracy, so don’t pay more if consistency will do.

If absolute accuracy is a concern, then traceability to standards such as those maintained by the National Institute of Standards & Technology (NIST) will also be important. Traceability, through working to secondary to primary standards is central to the quality standards compliance such as those defined by the ISO 9000 quality standard.

Why Calibrate?

There are generally three methods of calibrating industrial radiation thermometers. One method is to use a commercial blackbody simulator, an isothermally heated cavity with a relatively small aperture through which the radiation thermometer is sighted (Figure 7-1). As explained in the earlier chapter on “Theoretical Development,” this type of configuration approaches blackbody performance and its emissivity approaches unity. A standard thermocouple or resistance temperature detector (RTD) inside the cavity is used as the temperature reference. At higher temperatures, calibrated tungsten filament lamps are commonly used as references. A final alternative is to use a reference pyrometer whose calibration is known to be accurate, adjusting the output of the instrument being calibrated until it matches.

In any case, the radiation source must completely fill the instrument’s field of view in order to check the...
calibration output. If the field of view is not filled, the thermometer will read low. In some instruments, calibration against a blackbody reference standard may be internal—a chopper is used to alternate between exposing the detector to the blackbody source and the surface of interest. Effectively, this provides continuous recalibration and helps to eliminate errors due to drift.

**Blackbody Cavities**

Because calibration of a non-contact temperature sensor requires a source of blackbody radiation with a precise means of controlling and measuring the temperature of the source, the interior surface of a heated cavity constitutes a convenient form, since the intensity of radiation from it is essentially independent of the material and its surface condition.

In order for a blackbody cavity to work appropriately, the cavity must be isothermal; its emissivity must be known or sufficiently close to unity; and the standard reference thermocouple must be the same temperature as the cavity. Essentially, the blackbody calibration reference consists of a heated enclosure with a small aperture through which the interior surface can be viewed (Figure 7-1). In general, the larger the enclosure relative to the aperture, the more nearly unity emissivity is approached (Figure 7-2). Although the spherical cavity is the most commonly referenced shape, carefully proportioned cone- or wedge-shaped cavities also can approach unity emissivity.

In order to provide isothermal surroundings for the cavity, the following materials commonly are used:

- Stirred water bath for 30-100°C (86-212°F) temperature ranges;
- Aluminum core for 50-400°C (122-752°F) temperature ranges; and
- Stainless steel core for 350-1000°C (662-1832°F) temperature ranges.

And while blackbody cavities have their appeal, they also have some disadvantages. Some portable, battery-operated units can be used at low temperatures (less than 100°C), but blackbody cavities are, for the most part, relatively cumbersome and expensive. They also can take a long time to reach thermal equilibrium (30 minutes or more), slowing the calibration procedure significantly if a series of measurements is to be made.
Tungsten Filaments

As a working alternative to blackbody cavities, tungsten ribbon lamps, or tungsten strip lamps, are commonly used as standard sources (Figure 7-3). Tungsten strip lamps are highly reproducible sources of radiant energy and can be accurately calibrated in the 800°C to 2300°C range. They yield instantaneous and accurate adjustment and can be used at higher temperatures than those readily obtainable with most cavities.

Lamps, however, must be calibrated in turn against a blackbody standard; the user is typically provided with the relationship between electric current to the filament and its temperature. Emissivity varies with temperature and with wavelength, but material is well understood enough to convert apparent temperatures to actual.

Just as a blackbody cavity includes a NIST-traceable reference thermocouple, instrument calibration against a ribbon lamp also can be traced to NIST standards. In a primary calibration, done mostly by NIST itself, filament current is used to balance standard lamp brightness against the goldpoint temperature in a blackbody furnace, in accordance with the ITS-90. Typical uncertainties range from ±4°C at the gold point to ±40°C at 4000°C.

In secondary standard calibration, the output of a primary pyrometer, i.e., one calibrated at NIST, is compared with the output of a secondary pyrometer when sighted alternately on a tungsten strip lamp. Many systematic errors cancel out in this procedure and make it more practical for routine calibration.

References and Further Reading