CONTROL ENGINEERING ONLINE
Covering control, instrumentation, & automation systems worldwide
Cahners.

Making Contact with Temperature

Here is a look at the phenomenon itself, the basic measurement technologies available, and how industry is presently using them.

Jesse Yoder, Flow Research

Temperature is among the most—if not the most—measured of physical variables. However, defining temperature is not so easy. Humans primarily experience temperature as a feeling or sensation of hotness or coldness.

The temperature that we experience is an objective quality we feel as hot or cold. It is this quality that causes us to experience the sensation of heat or coldness.

Our feelings of hot and cold are caused by molecular motion, and temperature is a measure of the average kinetic energy of the molecules of a substance. The term "kinetic" means "having to do with motion," so another way of saying this is as follows. Temperature is a measure of the average energy of a substance due to the motion of the molecules in the substance. As the average motion increases, so does the temperature. And temperature decreases as the average motion is reduced.

Understanding temperature measurement requires knowing how two bodies at different temperatures interact. When two bodies are in thermal contact, a form of energy called heat flows from the warmer body to the cooler body. This energy transfer continues until the temperatures of the two bodies are equal. The transfer of heat energy ceases at that point.

Methods of measurement

Temperature is measured in a variety of ways. All methods of temperature measurement use some type of sensor. A temperature sensor has one or more properties that change in predictable ways as the temperature changes. The changing properties of the temperature sensor are interpreted as changes in temperature by a temperature scale, a voltmeter, a thermometer, or a similar device.

In industrial applications, four types of temperature sensors are frequently encountered:

- Thermocouples;
- Resistance temperature detectors (RTDs);
- Thermistors; and
- Infrared (noncontact) devices.

Thermocouples are the most widely used temperature sensors in industrial manufacturing environments. Thermocouples consist of two wires made of different metals joined at one end, called the measurement junction. At the other end of the conductors, a reference junction is formed. When the measurement junction and reference junction have different temperatures, a continuous current flows in the circuit. The resulting voltage is a function of the difference in temperature between the measurement and the reference junctions. The amount of voltage depends on the types of metals used. A voltmeter or other device is required to interpret the voltage reading as a temperature value.

Resistance temperature detectors (RTDs) make use of the fact that resistance to the flow of electricity in a wire changes with temperature. Platinum is the most commonly used wire material. There are two types of RTDs: wirewound and thin film.

Wirewound RTDs consist of wire wound on a bobbin, which is enclosed in glass. For thin-film RTDs, a film is etched onto a ceramic substrate, and sealed. RTDs are more accurate and stable than thermocouples, but cannot be used to measure extremely high temperatures.

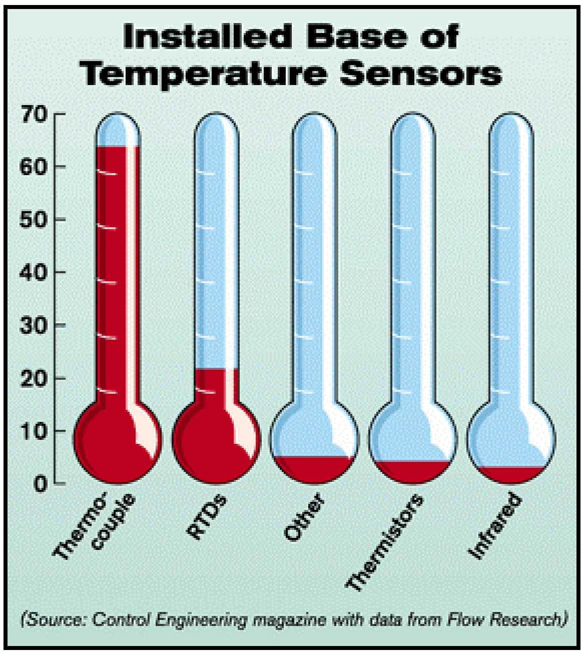
Like RTDs, **thermistors** also change resistance with changing temperatures, but they are more sensitive than either RTDs or thermocouples. Thermistors change their resistance much more significantly than RTDs with changing temperature. However, this change is highly nonlinear. Because of their extreme sensitivity and nonlinearity, thermistors are limited to measuring temperatures of a few hundred degrees Celsius. They are less rugged than RTDs, further limiting their application.

Infrared thermometers are used to measure temperature when contact measurement, using thermocouples, RTDs, or thermistors, is not possible. For example, they are used to measure the temperature of moving objects, such as moving machinery or a conveyor belt. They are also used where contamination is present, for hazardous reasons, or where the distance is too great for contact sensors. Infrared sensors detect the infrared energy given off by materials. The most common design includes a lens to focus the infrared energy onto a detector. The amount of infrared energy is then converted into a temperature measurement according to specifiable units.

Determining the installed base

In a study conducted by interview of 132 users and 250 suppliers over most of 1999, Flow Research (Wakefield, Mass.) and Ducker Research (Bloomfield Hills, Mich.) sought to determine the installed base of industrial temperature sensors. According to survey results, the installed base of temperature sensors is distributed as the first graphic shows.

Since the survey was focused on sensors as opposed to mechanical or hand-read thermometers, manual devices are not part of the survey. Hence the "Other" value of 6% should not be taken as a measure of all other types of temperature measurement devices. In fact, the survey made no attempt to quantify the number of bimetallic or liquid-in-glass thermometers, or integrated circuit temperature sensors, in use in manufacturing plants.



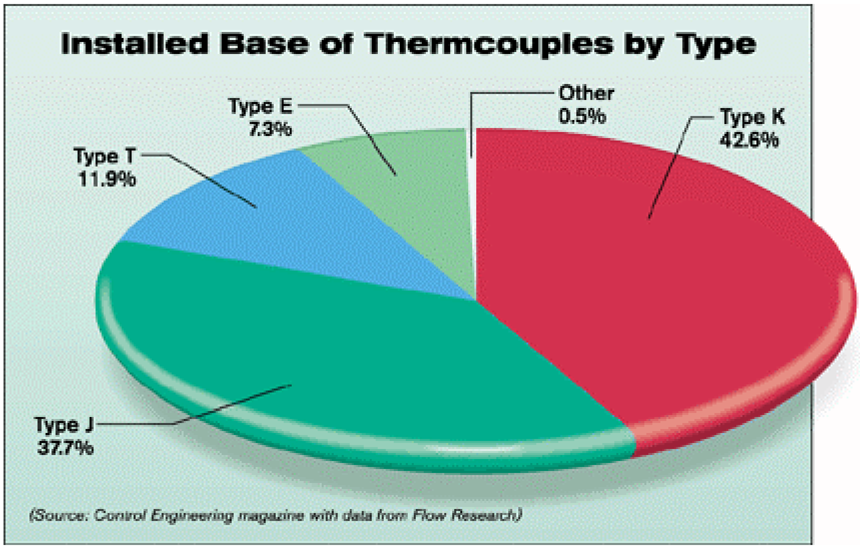
The oldest technologies dominate the temperature sensor market.

Most striking in the survey is the large proportion of thermocouples (64%) that form the installed base of temperature sensors. Such a large installed base of thermocouples creates a very large source of demand. While some thermocouple users are changing to RTDs, this is more likely to occur during new construction or plant renovation than during routine replacement. The large installed base of thermocouples anchors the thermocouple market by ensuring a stable source of continuing demand for them.

Sensor-type loyalty is strong. When asked if control engineers had substituted one type of temperature sensor for another in the past year, only 13% of those surveyed said they had. This means that, when replacements are made, 87% of the time a sensor is replaced with another of the same type. Considering that response with the 64% installed base of thermocouples, it is easy to understand the large and stable demand for thermocouples.

Looking at T/C types

Thermocouples are divided into several types, according to the combination of junction metals. These letter-designated types provide different mV outputs for given temperature ranges, providing flexibility for varying industrial applications.



Broad applicability and inherent linearity have made Type K and J thermocouples the most used temperature sensors in industry.

According to the second diagram, types K and J are used in far greater numbers than other junction types, such as T and E. Others include more specialized types like S, R, and B. Greater use of types K and J probably results from their high linearity and ability to provide a high mV over a given temperature range.

Moving toward RTDs

A shift is occurring among end-users away from thermocouples and towards RTDs. The trend,ongoing for a number of years, continues.

The change towards use of RTDs is driven by several factors. One is that RTDs are more accurate than thermocouples. Sensor accuracy has become increasingly important in the optimization of processes essential to corporate efficiency and competitiveness. Secondly, RTDs are more stable than thermocouples and are less subject to drift over time. Sensor maintenance and calibration is both costly and time consuming.

The switch from thermocouples to RTDs may not affect unit growth of temperature sensors, since it normally requires one RTD to replace one thermocouple. However, it may increase revenue growth of the temperature sensor market because RTDs, on average, cost more than thermocouples. This gradual shift is likely to continue over the next several years. Both thermocouple and RTD technologies have been around for a long time, and both will continue to be widely used.

Despite the changeover to RTDs, there are still many more thermocouples being shipped on a unit basis than RTDs.

One limitation to the impact of RTDs on thermocouples has to do with application. RTDs do not function properly at temperatures greater than 1,200 ºF. Therefore, in certain industries and extremely high-temperature applications—such as heat treating, oven control, jet engine testing, steel making, metal fabrication—RTDs cannot be used. Exotic metal—platinum and tungsten—thermocouples will continue to dominate in these high-temperature applications for the foreseeable future.

Within RTDs, a changeover is occurring from wirewound to thin-film devices. Wirewound RTDs are composed of a coil of wire wound around some type of core, usually ceramic. For thin-film RTDs, a film is etched onto a ceramic substrate and sealed. End-users are changing over to thin-film RTDs; technology improvements have increased performance and lowered cost.

Seeking new ways

It is easy to get the impression that everything about temperature measurement is already known. This is because temperaturesensing technologies have been around for many years, and not a lot of new methods seem to appear on the horizon.

Discoveries that led to thermocouples and RTDs were made in the mid-1800s, and infrared technology can trace its roots to around 1900.

Yet, advancements in temperature sensor technologies continue. Migration from thermocouples to RTDs results from improvements in RTD technology, combined with a heightened concern for accuracy.

The move from wirewound to thin-film RTD technology is a result of improvements in the latter new technology. One technology called "thin-wire" has been developed that makes it possible to place a temperature sensor in a hostile location, such as a turbine blade and provide real-time temperature data to improve engine performance. Breakthroughs have also occurred in measuring both extremely high and cryogenic temperatures.

In the area of temperature measurement, research focuses on developing new sensors for extreme applications. As temperature sensing manufacturers focus on basic sensor research, it's possible completely new temperature-measurement methods will be discovered

Relative Advantages of Contact Temperature Sensors

Quality	Thermocouples	RTDs	Thermistors
Temperature Range	-400 to 4,200 ºF	-200 to1,475 ºF	-176 to 392 ºF
Accuracy	Less accurate than RTD	More accurate than thermocouple	More accurate than RTD
Ruggedness	Highly rugged	Sensitive to shock	Not rugged
Linearity	Highly nonlinear	Somewhat nonlinear	Highly nonlinear
Drift	Subject to drift	Less subject to drift than t/c	Less subject to drift than t/c
Cold Junction	Required	None	None
Compensation Response	Fast	Relatively slow	Faster than RTDs
Cost	Low except for noble metal devices	Higher than thermocouples	Low

Source: Control Engineering with information from Flow Research