THERMOCOUPLE OR RTD?

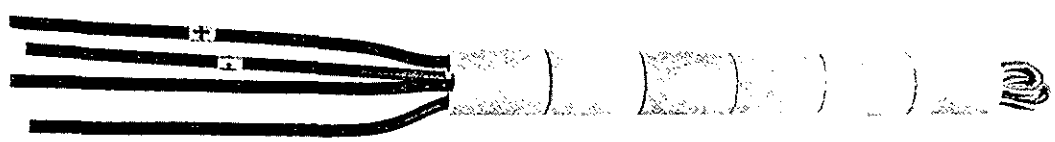

FIGURE 1. Twisted pair with butt weld at tip and ceramic bead insulation in simplest thermocouple type.

Temperature is the most measured variable in the process industries. Although more thermocouples are purchased today for process temperature measurement than any other sensor, a quiet "revolution" is slowly changing the mix of temperature sensors used; resistance temperature detectors are increasing in use in process industries due to some characteristics which make them better suited for certain applications.

THERMOCOUPLES, PAST

Early thermocouples tended to be fairly crude devices; two pieces of thermocouple material wire were twisted together with a butt weld at the tip, and ceramic beads or a fibrous material acted as insulation (Fig. 1). The thermocouple was generally placed in protection tubes from closed-end pipe (Fig. 2).

This type of thermocouple, still widely used, is inexpensive but has a variety of problems: If made from Iron *vs* Constantan (ISA Type J), the iron leg is subject to oxidation, which can throw the thermocouple out of calibration and lead to failure. If made from Chromel *vs* Alumel (ISA Type K), the Chromel leg is subject to carbide precipitation or "green rot", with eventual failure occurring quickly. Obviously, a better thermocouple was needed than these early Types J and K.

THERMOCOUPLES, PRESENT

About 30 years ago a method of encapsulating matched pairs of thermocouple wires inside a stainless-steel or nickel-alloy sheath and using mineral insulation, most often high-purity MgO was developed (Fig. 3). This was a major innovation, and is the method most often used today. Now, a thermocouple can be constructed which can be inserted directly into a process, and which can withstand the attacks of corrosive environments, high temperatures and mechanical damage.

Reprinted from MEASUREMENTS & CONTROL, June 1982

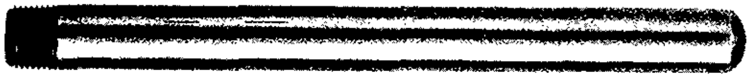

FIGURE 2. Protection tube fabricated from closed-end pipe.

This form of thermocouple can be made in various wire diameters (from less than .040" to .500), and with different sheath materials and lengths, which allow it to be tailored to the application. Some examples of present-day thermocouple usage and construction follow.

MINIATURE THERMOCOUPLES

Miniature thermocouples (Fig. 4) are relatively inexpensive. Typical applications include ovens, plastics processing machinery, jet-engine exhaust temperature, heat treating, food processing, etc.

Of particular interest is the jet-engine-exhaust thermocouple (Fig. 5), designed to re-

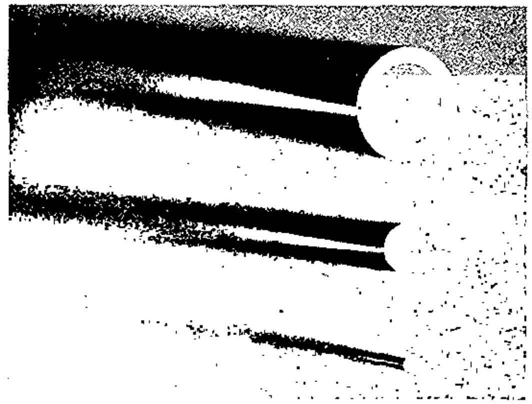

FIGURE 3. Thermocouple type uses stainless-steel or nickel-alloy sheath and mineral insulation.

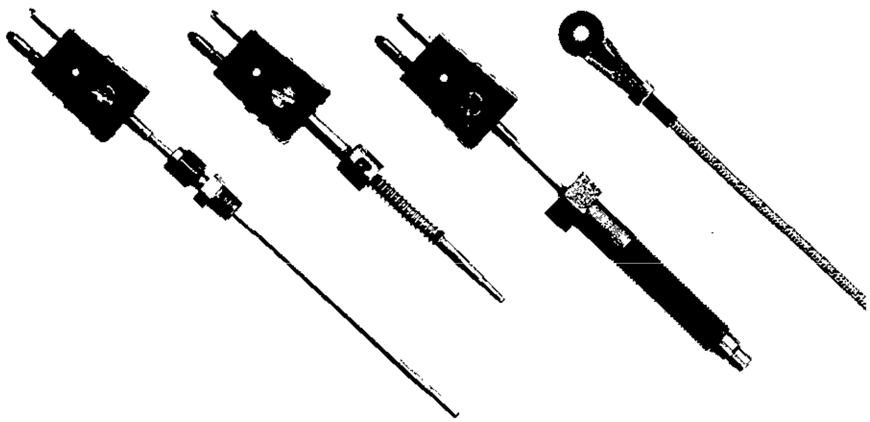

FIGURE 4. Miniature thermocouples.

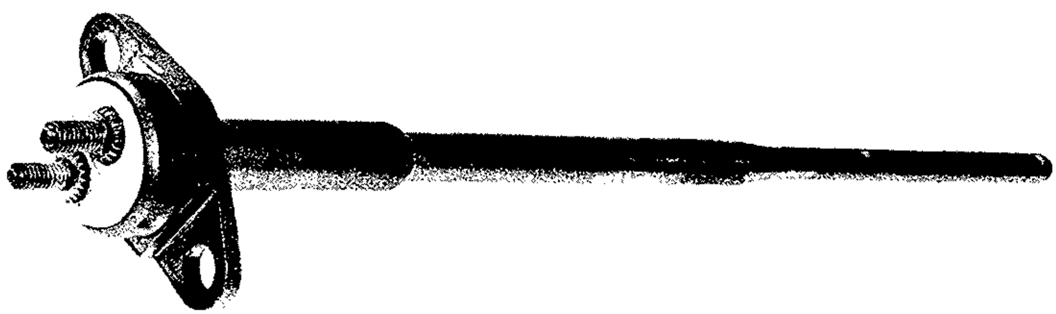

FIGURE 5. Jet-engine exhaust thermocouple must withstand high exhaust velocity, mechanical shock, vibration and cold-start to high-temperature in seconds.

FIGURE 6. Hypodermic needle thermocouple.

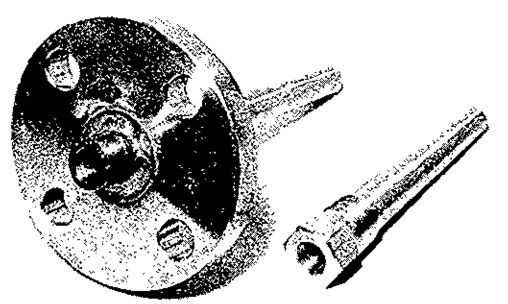

FIGURE 7. Industrial thermocouples often require additional protection provided by a thermowell.

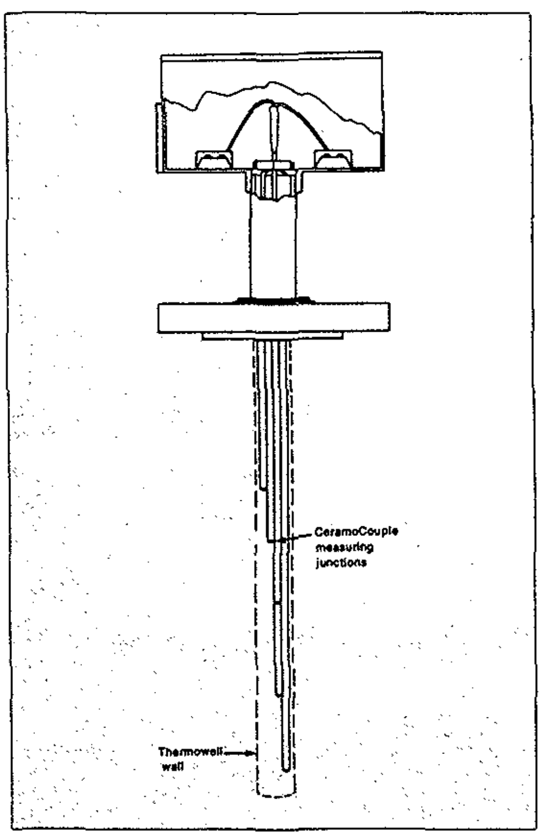

FIGURE 8. Multicouple for temperature profiling.

act quickly and to provide long life in an extremely harsh environment. High temperature is just one environmental problem; there is also high mechanical shock from vibration, high velocity of the exhaust, and shock of cold start to high operating temperatures in seconds.

Another interesting thermocouple design is the hypodermic needle style (Fig. 6), used in applications from measuring skin temperatures in laboratories to measuring frozen product temperatures in food processing plants. The small size features rapid response and high accuracy.

INDUSTRIAL THERMOCOUPLES

Industrial Thermocouples must be rugged; they often are inserted into process lines or pipes where flow velocity and pressure are such that additional protection is required. Thermowells (Fig. 7), often machined from either solid barstock (stainless steel or nickel alloy), are made with screwed, flanged, socket or weld-in and Van Stone construction.

Selecting the proper industrial thermocouple involves balancing many factors—process temperature, environment, fluid or gas pressure, pipe or vessel size, flow velocity, and more—to optimize sensor life and performance. Qualified vendors can assist the specifier by performing calculations based on computer-simulated conditions.

MULTICOUPLES

There is often need to measure a temperature "profile" of a tank, vessel or reactor. The method most often used is the multicouple (Fig. 8), consisting of a number of thermocouples, terminated in a junction box, positioned inside a long pipe thermowell at various points so that the operator can monitor the temperature profile of the vessel.

More sophisticated forms of multicouples are required where high pressure or long lengths are involved. The thermocouples can be spring-loaded to the inside wall of the pipe thermowell to insure good thermal response to temperature shifts. With a "guide tube", a thermocouple can be removed from the vessel while it is hot; the sensors are placed inside individual closed-end tubes which act as thermowells within the pipe. This system eliminates downtime in event of failure of a thermocouple, and also facilitates periodic maintenance. Manufacturers of these multicouples must follow ASME codes and perform various tests, such as pressure tests, dye-penetrant tests and X-ray tests to insure the integrity of the multicouple assembly.

THERMOCOUPLE, FUTURE

Thermocouples have remained basically similar for the past decade. However, challenging applications involving more exotic and higher-temperature processes have led to a few new developments. In the area of metallurgy, new *sheath alloys* and *coatings* have extended the range of applications and process conditions where thermocouples can be used. *Hard surfacing* and *aluminizing* provide increased protection for thermocouple assemblies in corrosive or abrasive environments, permitting use of thermocouples in new areas.

Work is being conducted on *film thermocouples*. In this form, a thermocouple material "ink" is placed on a substrate, much like semiconductor methods. This is still an experimental technique, in development.

Perhaps the biggest development in the recent past is the *Nicrosil-Nisil* (type N) thermocouple calibration. This new calibration exhibits better stability and high-temperature oxidation resistance than type K or other presently popular thermocouple calibrations. However, it is not yet widely used outside laboratory applications.

RTDs PAST

Use of Resistance Temperature Detectors (RTDs) has been slower in the United States than in Europe and other parts of the world—that is, the percent of usage is smaller in the U.S. than abroad. Perhaps two reasons are the thoughts that RTDs, while more accurate and stable than thermocouples, are too fragile and too expensive for the everyday industrial temperature-sensing use.

Traditionally, RTDs are constructed by *winding high-purity platinum, copper, nickel*, nickel-iron or other wire around an inert substrate such as glass or ceramic (Fig. 9). The result is an accurate, stable and repeatable temperature sensor. However, the relatively high per unit cost and fragility (compared with thermocouples) has led many to think of RTDs, especially those made of platinum, as suitable only for laboratory use or temperature standards.

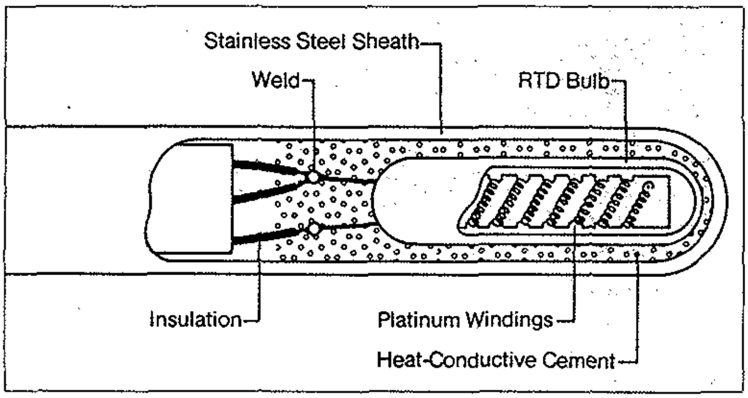

FIGURE 9. Platinum RTD.

TABLE 1. ACCURACY OF PRTD VS THERMOCOUPLE

Temp, °C	Standard DIN Tolerance PRTD, ±°C	Type T ±°C	ISA Standard-Grade Thermocouple Type J ±°C	Type K ±°C
−100	0.7	1.7	--	--
0	0.3	0.8	2.2	2.2
100	0.5	0.9	2.2	2.2
200	1.1	1.6	2.2	2.2
300	1.7	2.4	2.4	2.4
400	2.3	3.1	3.1	3.1
500	3.0	3.9	3.9	3.9

RTDs PRESENT

Advances in RTD element and probe construction techniques have served to make them more rugged and cost effective. This, along with an increasing need to monitor process temperatures more closely, is leading to increasing use of RTDs by process and power industries.

The most commonly used *element material* is platinum with a resistance of 100 ohms @ 0°C and a temperature coefficient (Alpha) of 0.00385 ohms/ohm/°C.

Other element materials also used are *copper, nickel* and *nickel-iron*. Platinum elements predominate because of their wider range, and because platinum is the most repeatable and stable of all metals.

The biggest reason for increased usage of the platinum RTD is inherent accuracy. Compared to thermocouples, however, this accuracy is over smaller temperature spans at lower maximum temperature limits. Table 1 compares the accuracy of a standard DIN

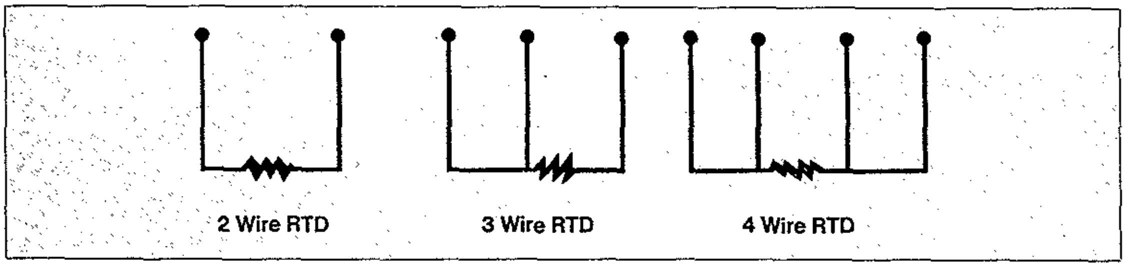

FIGURE 10. The RTD can have 2-wire, 3-wire or 4-wire leads, depending on amount of lead-resistance compensation required.

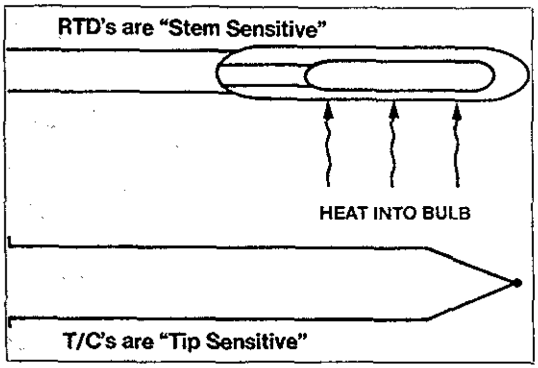

FIGURE 11. Sensitive length of RTD is longer than that of "Tip-sensitive" thermocouple.

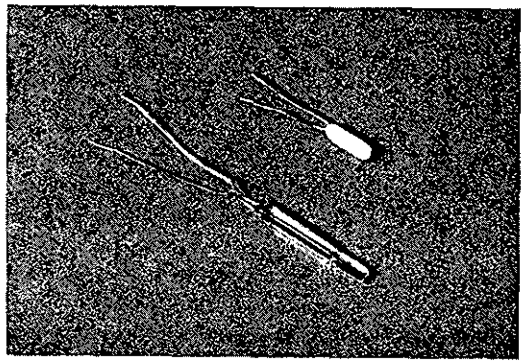

FIGURE 14. RTDs made with "thin-film" technology.

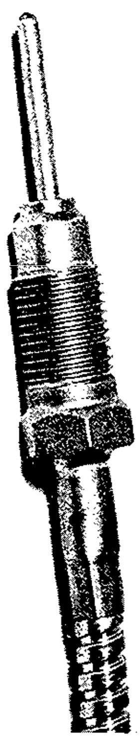

FIGURE 12. (left) RTD for high-pressure polymer extrusion line.
FIGURE 13. (right) RTD surface-temperature assembly.

Tolerance Platinum RTD with those of the more popular thermocouple calibrations.

As Table 1 demonstrates, PRTDs can be more than twice as accurate as standard-grade thermocouples, especially at temperatures of 200°C and below. This, along with the higher stability and repeatability of the platinum RTD, suggests its use where accurate measurements are required. RTDs also have a higher and more linear output than thermocouples, making them easier to interface with today's data-acquisition and computer-controlled systems.

RTD CONSTRUCTION

Miniature RTDs can be made with protective sheath O.D.s as small as 1/8". They can have 2, 3 or 4 lead wires, depending on the amount of lead-resistance compensation required (Fig. 10); the 3-wire form is the most popular.

Special problems arise where the immersion depth is shallow because the RTD sensing element is longer than the tip-sensitive thermocouple (Fig. 11). This means that the RTD element itself must be small. The RTD is said to be "stem sensitive."

Figure 12 is an example of a custom-made RTD for a high-pressure polymer extrusion line. The criteria involved here included

TABLE 2. COMPARISON OF THERMOCOUPLE AND PRTD

CRITERION	Standard-Grade Thermocouple ISA J	ISA K	Standard DIN Tolerance PRTD
Accuracy			
@ 0°C	±2.2°C	±2.2°C	±0.3°C
100°C	±2.2°C	±2.2°C	±0.5°C
500°C	±3.9°C	±3.9°C	±3.0°C
Time Constant	1.7 sec*	1.7 sec	5.0 sec.**
Tip Sensitive	Yes	Yes	No
Upper Temp Limit (Approx.)	870°C	1300°C	800°C

*1/4" OD Probe, grounded junction **1/4" O D Probe

withstanding high-pressure steam at 300°C, and an immersion depth of less than 1/2", which meant that the RTD element had to be small.

Figure 13 demonstrates a gasket RTD surface temperature assembly, for use on a paper machine. Previously only thermocouples, were used. The RTD element used was extremely small, and care had to be taken to provide proper thermal transfer as well as physical support.

RTDs FUTURE

Several developments in the field of resistance thermometry promise to further increase RTD use in industry. The most interesting advance is the "thick film" or "thin film" technology. Basically, RTD elements made by these processes have a platinum "ink" deposited on an inert substrate, like semiconductor techniques. The result is a smaller RTD element (Fig. 14) which can be made in a variety of shapes to suit the application. Unlike traditional wirewound types, these elements can be mass produced to some degree, which brings down the cost.

The designer of RTD probes will have more flexibility than in the past. Since these elements are smaller, RTD probes can be made more tip sensitive, and the ruggedness of the probes increased because these elements do not have fragile wire windings.

RTD vs THERMOCOUPLE

Selection of the proper temperature sensor for a given application is not simple; the many variables involved means that the specifier must carefully define his process parameters and his control or monitoring requirements. Happily, the wide variety of temperature sensors available, both thermocouple and RTD, allows selection of the best sensor for measurement optimization.

Table 2 is a brief comparison of standard-grade ISA J and K calibration thermocouples with a standard DIN-tolerance 100-ohm at 0°C platinum RTD. As can be seen, both offer advantages in certain areas. All values listed are typical, representative of the two sensor types.

As shown, RTDs are generally more accurate; however, the differences tend to disappear above 500°C. Thermocouples have a much faster response time, on the order of 3 times faster, than RTDs. Thermocouples are tip sensitive wherever RTDs are "stem sensitive", making thermocouples more suitable for point sensing. Thermocouples generally have a higher upper temperature limit (although this is calibration dependent), making them the sensor of choice in elevated temperature applications.

It is obvious that each type has advantages for specific requirements of accuracy, range, and specific application factors. □