Recent Advances in Industrial Platinum Resistance Thermometry

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The modern platinum resistance thermometer provides the most accurate and versatile method of industrial temperature measurement and control. This article gives details of a new design of platinum resistance thermometer element of small dimensions and good stability. It also describes a range of complete thermometers based on these elements together with a resistance-bridge system used for signal conditioning when the thermometers are used in data-logging or computer controlled systems.

Two principal factors have contributed to a recent large increase in the use of platinum resistance thermometers in industry. On the one hand new techniques of manufacture have produced thermometers that are smaller and more robust than was possible in the past so that it becomes feasible to specify resistance thermometers for applications which have hitherto been the province of the thermocouple. On the other hand the continual striving after improved accuracy of measurement and control has received an additional impetus with the introduction of central data-logging and computing equipment. For these applications the resistance thermometer confers the advantages of better reproducibility and larger output signal coupled with the ability to scale the output to fit the requirements of the instrumentation.

**Thermometer Designs**

Modern methods of refining platinum have put materials of extreme and dependable purity at the disposal of the manufacturer of resistance thermometers in a wide range of wire diameters down to 0.0004 inch or even smaller. These small diameters were often, in the past, associated with high impurity content as a result of material picked up from the drawing dies; this problem has now been
largely overcome, although some surface etching is still normally necessary to achieve the highest temperature coefficients.

The problem facing the thermometer manufacturer is to maintain the high temperature coefficient and good stability inherent in the pure platinum, while at the same time providing the mechanical support needed to enable the element to survive the vibration and shock conditions of military and industrial use. This support is the more necessary in that pure annealed platinum is extremely soft and hence mechanically weak. This problem is usually solved by some sort of compromise since, in general, higher vibration levels will require greater degrees of support, with inevitably poorer electrical stability. At one extreme are found interpolation standard thermometers with almost unsupported coils, since the ultimate in stability is required under conditions of careful laboratory handling, while at the other extreme thermometers for use in aircraft engines may have the platinum encapsulated over the whole length. Many compromise constructions between these extremes have been
proposed; for example in some aircraft thermometers the platinum coil is wound on an insulated platinum tube to avoid differential expansion effects (an example of this is shown in Fig. 1), but the construction described below (1) has proved extremely useful and versatile in a very wide range of industrial applications.

The main features of the construction may be appreciated from Fig. 3. The helical element is embedded in a glazing compound which attaches it to the high-alumina ceramic over approximately one-sixth of the circumference of each turn. The result of this is that the greater part of the coil is free to expand and contract, but is sufficiently firmly attached to withstand the levels of vibration normally encountered in industrial processes. The fact that part of the coil is encapsulated necessarily means that there is some reduction in temperature coefficient and degradation in stability as compared with the unsupported platinum wire. It might be somewhat naive to suppose that the characteristics should fall roughly one-sixth of the way between those of the unsupported and the fully encapsulated thermometer, but the value obtained for \( \alpha \), the mean temperature coefficient between 0°C and 100°C, of 0.003916 is in approximately this relationship with the typical figures of 0.003925 for unsupported wire and 0.003850 to 0.003880 for fully encapsulated constructions. Stability figures do not admit of such facile juggling, but these also lie closer to those of unsupported than those of encapsulated wires. This stability is illustrated by the following figures obtained on a sample batch of four thermometers:

<table>
<thead>
<tr>
<th>Stability Tests on a Batch of Four Thermometers</th>
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<tr>
<td>( R^0 = \text{Resistance in ohms at } 0°C; \ R_{100} = \text{Resistance in ohms at } 100°C )</td>
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</table>

<table>
<thead>
<tr>
<th>Thermometer</th>
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</thead>
<tbody>
<tr>
<td>Initial Values</td>
<td>( R_0 )</td>
<td>( R_{100} )</td>
<td>( R_0 )</td>
<td>( R_{100} )</td>
</tr>
<tr>
<td>1</td>
<td>99.998</td>
<td>139.133</td>
<td>99.988</td>
<td>139.129</td>
</tr>
<tr>
<td>After 10 cycles from 20°C to 400°C, and 250 hours at 400°C</td>
<td>99.995</td>
<td>139.126</td>
<td>99.982</td>
<td>139.109</td>
</tr>
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The wide range of shapes and sizes of platinum thermometers that these and other techniques have made possible means that an ever-increasing number of temperature measuring systems now use resistance temperature sensors. Some of the special shapes of resistance thermometer that have been produced for a variety of industrial, aircraft and medical applications are shown in the illustrations. Fig. 2 shows a range of industrial immersion thermometers, some suitable for direct insertion and some for use in pockets (thermo-wells). These thermometers all use elements having the construction shown in Fig. 3 and can be produced in sheath diameters down to 0.093 inch. Fig. 4 shows thermometers for metal or bearing temperature sensing. The latter unit has found wide application in metal temperature sensing because of the extreme ease of installation and the wide temperature-range (up to 650°C) covered. Fig. 5 shows on the left a sensor incorporating the same basic element construction for surface temperature sensing in wing-skin temperature measurements in an aircraft anti-icing system, and on the right two small surface temperature sensors which, though not using exactly the same element construction, retain the concept of an only partially constrained platinum helix. Fig. 6 shows thermometers designed for medical and pathological work and based on the standard range of hypodermic needles.

**Bridge Designs**

When resistance thermometers are used in systems requiring the high accuracy called for in computer control, some of the precautions normally associated only with
precision laboratory measurements become necessary. The most important is the elimination of lead resistance effects; this has, over the years, received considerable attention and systems using compensating loops and three-wire connections have been widely used in industry, while four-wire, current and potential lead connections have normally only been employed in standards work. This last connection scheme, however, has the capability of providing the highest possible measurement accuracy and its use is gradually becoming essential to obtain the accuracies envisaged, for example, by the recent British Standard BS1904:1964.

When resistance thermometers are used in association with an analogue-to-digital converter or computer it is convenient to provide a voltage output representing the temperature. This is normally achieved by using some variant of the Wheatstone bridge fed from a stable power supply and reading the out-of-balance voltage. The Kelvin double bridge answers both the requirements for a voltage output and for a current and potential lead connection; it is shown in Fig. 7.

The basic principle is that the leads incorporated in the bridge arms are in series with fixed resistors having values very large compared to the lead resistances so that moderate changes in lead resistance have negligible effects on the total series resistance value. Thus N and J are large compared with L₁ and L₂ respectively, and L₄ is in the output circuit in series with the recorder or indicator, which has a large input impedance. The bridge is designed so that very little current flows through L₄ when lead resistances are at the design values and, when lead resistances vary, L₄ tends to equalise the voltage across the top of the bridge. This configuration makes it feasible to locate the sensor several thousand feet from the bridge and recorder or indicator.

A particularly versatile conditioning unit of this type is shown in Fig. 8; this is a 10-channel bridge chassis to which the resistance thermometers are connected and which can accept up to ten plug-in Kelvin double bridge modules. These are arranged to convert the resistance change of the sensor, over a specified temperature range, to a 0 to 100mV d.c. output signal. This standard signal is suitable for most data-loggers and computers and demonstrates one of the advantages of resistance thermometry; this signal can be made to represent a different temperature range using the same sensor by plugging in a different resistance bridge.

Systems of this sort have been accepted for use in data-logging applications in power stations, nuclear plants and chemical installations to give system accuracies of better than 0.25 per cent overall in the temperature range 0 to 600°C with a wide variety of thermometer shapes and configurations.

One of the first large scale applications of this system in computer control will be at Fawley Power Station, near Southampton, which will employ resistance thermometers in approximately 2000 temperature measuring channels, some 1000 of which will be used with these plug-in bridge units to provide information to the computer.
The modern platinum resistance thermometer has overcome virtually all the obstacles that have hitherto prevented its widespread use and now provides the most accurate and versatile method of precise industrial temperature measurement and control over the greater part of the normal spectrum of process temperatures. Temperatures from $-200^\circ$C to $+500^\circ$C are a matter of routine. Above this range to $+750^\circ$C some extra precautions are needed, while special units are being introduced to cover temperatures up to approximately $1000^\circ$C.

Reference
1 B.P. 959,368; 959,369; U.S.P. 3,114,125

Petrochemicals by Platinum Reforming

WORLD'S LARGEST AROMATICS PLANT

The world's largest aromatics petrochemical plant recently began production in Puerto Rico. Operated by Commonwealth Petrochemicals Inc., a subsidiary of Commonwealth Oil Refining Company, the plant receives raw naphtha feedstock both from the parent company's refinery and by tanker from Venezuela. The naphtha is fed to a Unifining process unit where it is catalytically desulphurised, and thence to a Platforming unit where it is reformed over a platinum catalyst to produce a high yield of aromatics. These are separated in a Sulfolane unit and finally produced as high purity benzene, toluene, ortho-xylene and mixed xylenes. The total annual capacity of the plant is 172 million gallons of aromatics. Five of the plant's major units were designed by Universal Oil Products Company.

The aromatics complex at the new Puerto Rico plant of Commonwealth Petrochemicals Inc.