The Platinum Resistance Thermometer

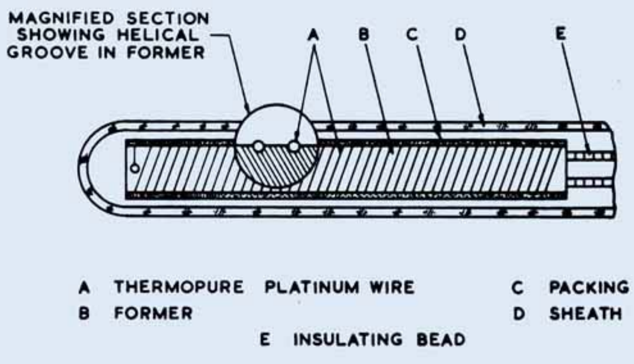
A REVIEW OF ITS CONSTRUCTION AND APPLICATIONS

By Rodney Price

The platinum resistance thermometer is a versatile instrument for temperature measurement in the range from $-200°$ to $1000°C$. It is used both for precision measurements of the highest accuracy and for routine industrial work. This article discusses the development and construction of resistance thermometers and their uses in a wide range of industries.

The platinum resistance thermometer—in which the principle of measurement is the variation in the resistance of a platinum wire as a function of temperature—is generally accepted as the most accurate temperature measuring instrument available. Its sensitivity and reliability are evident from the fact that it was first used in 1928 to define the International Temperature Scale from $-190°$ to 660°C and has thus been the primary international standard for over thirty years. But it has other advantages that find many and increasing applications in industry. It is particularly suitable where measurements are to be made over a relatively narrow range of temperature, where the point of measurement is some distance from the recording instrument, and where there are several measuring points and readings are required at one central instrument panel. In addition to the measurement of elevated temperatures, the platinum resistance thermometer is also finding a number of applications where the accurate determination or control of sub-zero temperatures is needed.

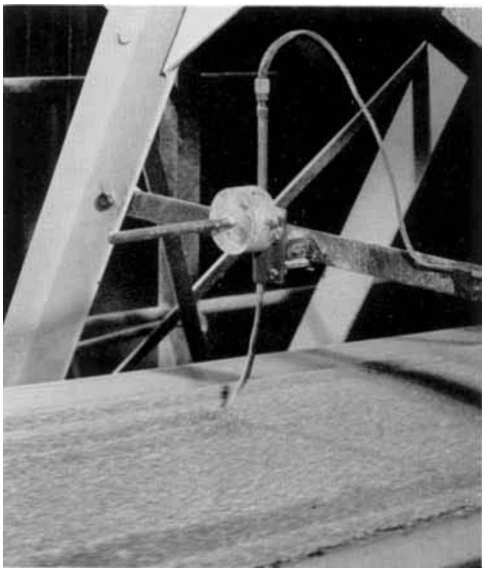
The operation of the resistance thermometer depends upon two characteristics of platinum—first the simple relationship between its resistance and its temperature, and secondly the high purity, stability and reproducibility of the specially prepared platinum employed for this purpose. The requirements of the International Temperature Scale of 1948 for the purity and physical



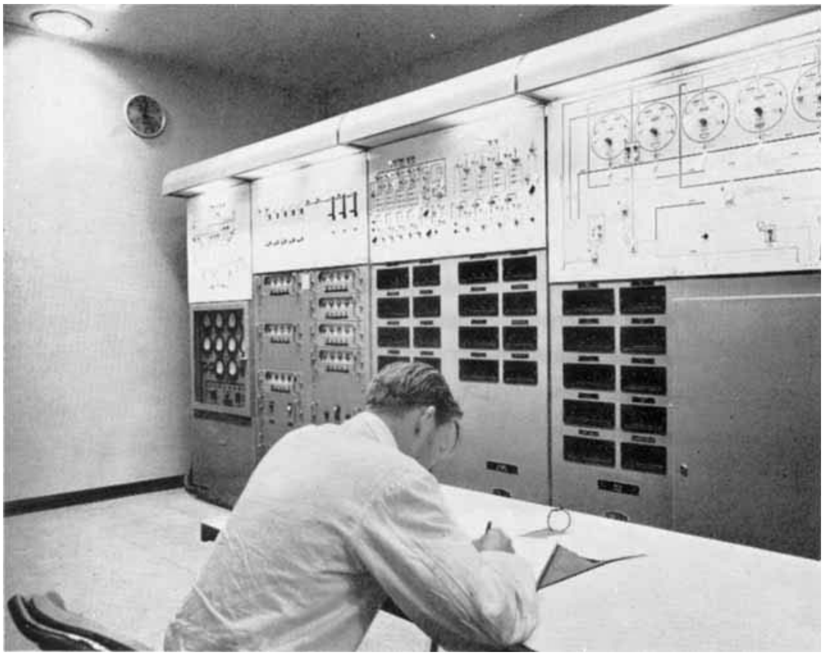
Section of a typical platinum resistance thermometer element, comprising a former of ceramic, glass or metal wound with fine Thermopure platinum wire. The sheath may be made of glass or metal according to the conditions of service.

condition of platinum to be used in resistance thermometry are based upon the change in resistance between 0° and 100°C, this range being known as the fundamental interval: the ratio R_{100}/R_0 is required to be greater than 1.3910. British Standard 1904 : 1952 on Commercial Platinum Resistance Thermometer Elements calls for a value not less than 1.390.

Any impurity in platinum lowers its temperature coefficient of resistance, and this characteristic of the metal is in fact the most sensitive indication of its purity. For resistance thermometry, therefore, extreme precautions have to be taken not only in the preparation and melting of the platinum but in its subsequent drawing to fine wire in order to maintain an exceptionally high state of purity and complete freedom from contamination during later processing. The special grade of metal prepared, known as JMC Thermopure platinum, consistently gives



Checking temperature in the production of granular fertilizer, flowing at 25 tons per hour on a conveyor belt, in the Ipswich works of Fisons Limited. The platinum resistance thermometer, by Sangamo Weston Limited, is sheathed with nylon tube.



The central control panel in J. Lyons & Company's new ice-cream factory at Greenford indicates continuous measurements of temperature, weight and sterilisation control. By automatic scanning and digital display, the black panels in the centre of the picture show temperature and weight. Temperatures from 0° to 60°C are measured with platinum resistance thermometers by Elliott Brothers (London) Ltd., who also supplied this part of the control panel.

A physicist in the Johnson Matthey Process Control Laboratory determining the temperature coefficient of resistance between 0° and and 100°C of the Thermopure platinum produced specially for resistance thermometry.

values greater than 1.3923 for the ratio R_{100}/R_0 and provides a sound basis for the design and construction of accurate and reliable thermometers.

Early History

The late Professor H. L. Callendar may fairly be regarded as the father of platinum resistance thermometry; the fundamentals of the thermometers in use today are unchanged from those he described in 1887, when as a young research worker of only 23 at the Cavendish Laboratory, Cambridge, he published a paper "On the Practical Measurement of Temperature" (1). This was followed by several other papers which he contributed on the same subject during the next few years.

The resistance thermometer had in fact been introduced by C. W. (later Sir William) Siemens. In a Bakerian lecture to the Royal Society in 1871 (2) Siemens had explained the theory of the method and described instruments capable of indicating temperatures up to 1000°C. The advantages of this device were quickly appreciated, and a distinguished committee of the British Association was appointed to test the instruments and report upon them. Their report (3), published in 1874, disclosed that on heating to temperatures of about 800°C the resistance of the instrument increased continuously and that the platinum wire underwent rapid deterioration.

Callendar became interested in the subject and found that the platinum wires he used did *not* undergo such changes even when subjected to much more severe tests than those applied by the committee. He was able, however, to reproduce the effects they had observed and to show that they were not

Professor H. L. Callendar

The platinum resistance thermometer was developed into a successful and accurate instrument by Callendar. A biographical note by his son appears on the facing page.

inherent in the method but were merely incidental to the particular form of instrument on which they had experimented. In particular, he showed that the clay used for the former, or some constituent of it, had attacked the platinum, while the iron protection tube—or even traces of volatile metallic impurities in the iron—had also been responsible. He found that if the wire was properly protected from strain and from contamination the instrument could be made practically free from change of zero, even at very high temperatures. By winding the wire on a thin plate of mica, by fusing platinum connecting wires on to the wire of the coil, and by protecting the element with a hard-glazed porcelain tube, Callendar was able to construct resistance thermometers that completely restored confidence in the instrument.

By 1890 the manufacture of platinum resistance thermometers had begun by the Cambridge Scientific Instrument Company, in close collaboration with Professor Callendar and Dr. E. H. Griffiths. Callendar carried out a great deal of research to establish the constancy of the relation between the resistance of a platinum wire and its temperature, and this work, together with his four-lead method of compensation, established the accuracy and reliability of the instrument.

The earliest record of an important use in industry was in 1891, when Sir Robert Mond,

Professor H. L. Callendar and the Platinum Resistance Thermometer

A BIOGRAPHICAL NOTE BY DR. L. H. CALLENDAR

The platinum resistance thermometer, the most accurate and sensitive means of temperature measurement, was introduced and developed by the late Professor H. L. Callendar, C.B.E., F.R.S.

In October 1885, Callendar, having taken a double First in Classics and Mathematics at Cambridge University, started as a research physicist under Professor J. J. Thompson to work on the variation of the electrical resistance of platinum as a means of measuring temperature. He was so quickly successful in solving the problem that he was able to present his first results to the Royal Society in June 1886 and publish a full dissertation on the matter in the Philosophical Transactions of the Royal Society in 1887. He was elected a Fellow of Trinity College, Cambridge, for his research on this subject.

Before this time, the gas thermometer was the theoretical standard of temperature, and the mercury thermometer with its limited range was the only practical instrument but was far too fragile for many purposes. Before Callendar, others had tried without success to use metals to make accurate thermometers but he brought to the problem a finer skill and inventiveness as shown in many ways. He first had the idea of sealing the platinum wire he was testing inside the bulb of the gas thermometer he had made as a standard, thus getting a perfect comparison between the two; he overcame previous troubles, such as the shifting zero, by using very pure platinum and by ensuring that the wire was free from strain, and the uncertainty of the resistance of the leads by fitting duplicate leads.

Thus Callendar gave to science a new tool for accurate temperature measurement. In his 1887 paper he advocated platinum as the ideal temperature standard up to at least 1200°C. He was invited to become a member of the Electrical Standards Committee of the British Association, and in 1899 put forward his proposals in detail. He showed that the gas thermometer had given results so discordant as greatly to retard the progress of research. On the other hand, platinum thermometers standardised at selected fixed points easily gave a consistency of one-tenth of a degree at 1000°C.

Under his supervision standard thermometers were made at the National Physical Laboratory and submitted to long and careful testing. The results fully confirmed Callendar's claims, and led to the establishment of the platinum resistance thermometer as a means of defining a major portion of the International Temperature Scale.

Callendar occupied the new Chair of Physics at McGill University, Montreal, from 1893 to 1898, when he returned to England to become Professor of Physics at University College, London. In 1902 he was appointed to the Professorship of Physics at the Royal College of Science, London. He died in 1930 at the age of 67.

working with Callendar, introduced the thermometers at one of his works. In the following year Callendar, working with Professor W. C. Roberts-Austen in the laboratory of the Royal Mint, made the first accurate determination of the melting points of the purest gold and silver then available. In describing this work in a lecture to the Royal Institute Professor Roberts-Austen said "I am satisfied that at temperatures about 1000°C the comparative results afforded by this method are accurate to the tenth of a degree, a result which would certainly have been deemed impossible a year or two ago".

In 1892 platinum thermometers were used in blast furnaces by Sir Lowthian Bell, while a little later some 65 thermometers and recorders were installed on the annealing furnaces at John Lysaght's sheet steel works at Newport, Monmouthshire. Some of these instruments were in use for as long as 50 years.

In 1900 the Practical Temperature Standards Sub-committee of the British Association agreed:

(1) That a particular sample of platinum wire be selected (Mr. Matthey of Johnson and Matthey had now supplied the Committee with two samples of very pure wire, which on test gave excellent results by the Callendar difference formula).

(2) That Professor Callendar and Mr. Glazebrook be requested to consider further the selection of wires for the construction of a number of platinum resistance thermometers for standard tests.

Six thermometers were accordingly made at the National Physical Laboratory and submitted to a long programme of testing by Harker and Chappuis (4). It was shown that platinum in porcelain thermometers could be heated and cooled between 0° and 1000°C for three months without measurable alteration in the zero of the instruments. This fully established the absolute reliability of the platinum resistance thermometer and confirmed Callendar's original claims put forward in his paper in 1887.

In later years other manufactures of scientific instruments also came into the field, and today a wide range of types is available to meet the many varied conditions encountered in industry. These applications, as will be seen later, include temperature recording or control in the production of liquid oxygen and nitrogen, of chemicals, and of rubber, in the storage of refrigerated meat and fruit and of timber and coal, and in space heating and ventilation.

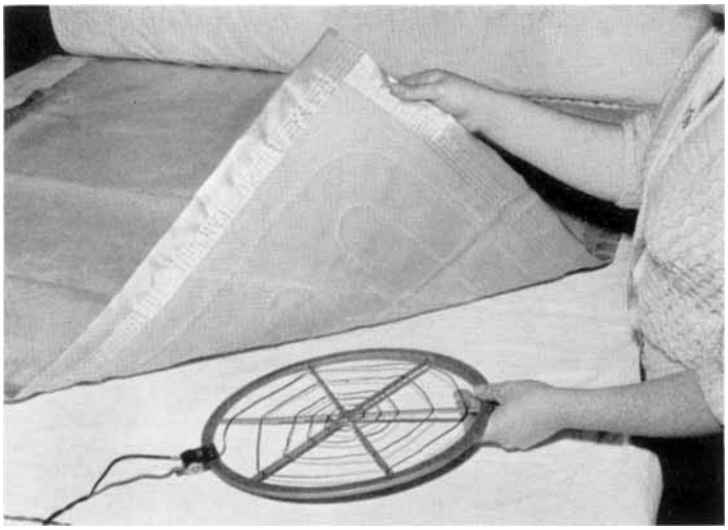
Design and Construction

As well as on the very high purity of the special Thermopure platinum wire provided for this purpose, the accuracy and stability of resistance thermometers depend upon the care given to their design and construction.

Great care has to be exercised to avoid contamination of the platinum element and to minimise stressing the wire in order not to reduce its temperature coefficient of resistance.

The ideal mounting for the element wire is one which minimises the strain caused in the wire by thermal expansion and contraction of the winding former. Callendar devised a former of two strips of mica assembled as a cross with notches cut in the edge of the strips to hold the wire in place. T. S. Sligh (5), of the U.S. Bureau of Standards, developed this design so that strain is further reduced. In another construction described by C. H. Meyers (6), also of the Bureau of Standards, the wire is first wound into a fine helix and then this helix is wound on to a former. This produces a compact winding particularly useful for aircraft instruments. J. A. Hall (7), of the National Physical Laboratory, described a construction in which the element is wound on a fused quartz frame in a hermetically sealed envelope, while his colleague, C. R. Barber (8), has described a thermometer of very small dimensions in which a formless coil is contained in a fine glass U-tube. The same author has also described a platinum-sheathed 2½-mm diameter thermometer for use at low temperatures (9).

The selection of suitable protection for the winding depends on the range of tempera-



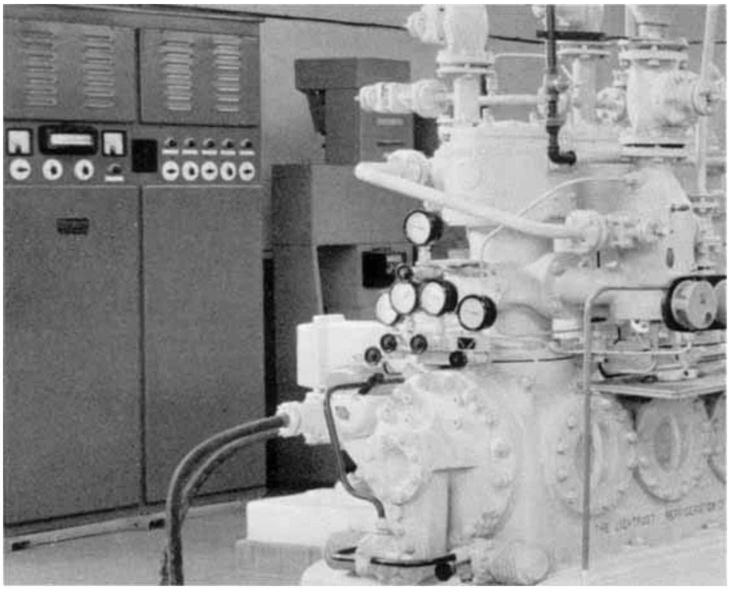
Morphy-Richards' electric blankets are tested at temperatures up to 90°C with one of a set of platinum resistance thermometers and multipoint recorders supplied by the Cambridge Instrument Co. Ltd. The sheathed sensitive element, made from silk-covered Thermopure platinum wire, may be seen formed in a spiral attached to a wheel-shaped frame.

tures to be measured, the accuracy and life required, and the corrosive nature of the surroundings. Some elements are sealed into glass sheaths; others are protected by mild-steel, brass, copper, stainless-steel or platinum sheaths. For some work, such as refrigerated cargo ships, when speed of response must be sacrificed to protection against corrosion, metal sheaths are completely covered with vulcanised rubber.

To ensure stability it is important to anneal the platinum coil after it has been formed. The International Temperature Scale recommends that standard resistance thermometers should be annealed in air at a temperature higher than the highest temperature at which they are to be used, and in any case at not less than 450°C. R. J. Corruccini (10), of the National Bureau of Standards, suggests that rapid cooling after annealing is undesirable because it may decrease the value of the temperature coefficient of resistance.

Silk-covered or synthetic-enamelled wire is used to make commercial thermometers to measure low temperatures, but silk covering produces strain in platinum wire, the effect of which upon its resistance characteristics cannot be entirely removed owing to the

Dr. H. Lister, the glaciologist of the Trans-Antarctic Expedition led by Sir Vivian Fuchs, using a platinum resistance thermometer to measure temperatures from −15° to −60°C at different depths in the ice. The photograph was taken at the advance base "South Ice", 4,400 feet above sea level and 300 miles south of Shackleton on the Weddell Sea.



A multi-point indicator working in conjunction with four platinum resistance thermometers by The Foster Instrument Co. Ltd. in one of the cold storage plants of Birds Eye Foods Ltd.

impossibility of heating the wire to a sufficiently high temperature. British Standard 1904:1952 states that the ratio R_{100}/R_0 for silk-covered wire should be not less than 1.385. The use of a synthetic epoxy-base enamel developed by Johnson Matthey and known as Diamel similarly limits the annealing temperature, but very little strain is caused by the enamelling process and Diamel-covered wire may be used up to 130°C. Values greater than 1.3910 for the ratio R_{100}/R_0 for Diamel-covered Thermopure platinum wire are obtainable.

Although platinum is resistant to a wide range of acids and other reagents, it is desirable to be familiar with the conditions in which the metal is attacked. It rapidly becomes brittle if it is heated in contact with phosphorus, arsenic, antimony, selenium or tellurium. A combination of traces of sulphur and silica or silicates will attack platinum in the presence of carbon, hydrogen or other reducing agent. Platinum is attacked by nearly all molten metals and by their vapours. To prevent contamination of the platinum wire, therefore, all parts of the thermometer should be clean. The selection of a suitable process depends on the materials used in construction, but a typical method is to wash all parts in benzene, boil in dilute nitric acid and wash several times in distilled water. Finally, after assembly and just before annealing, the platinum coil is washed in benzene.

British Standard 1904 recommends that to avoid significant heating of platinum wire being tested in air for use in commercial thermometers, the measuring current should not exceed 2 milliamperes per 0.001 inch of wire diameter. The heating effect of the measuring current depends on the heat conduction of the materials of the thermometer and of its surroundings, and is proportional to the square of the current.

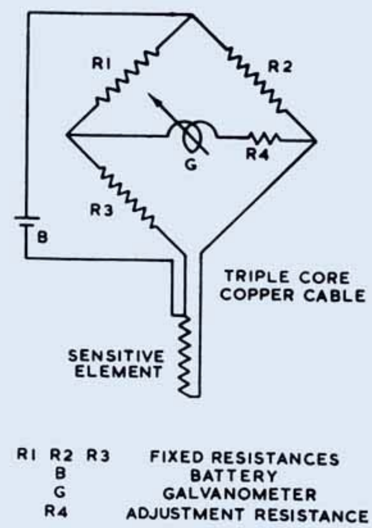
Measurement of Resistance

For very accurate temperature measurement, say to 0.001°C, special precaution must naturally be taken to remove every source of possible error. An excellent account of the laboratory procedure involved in this class of work has been given by J. A. Hall (11) and this will not be discussed further here. For a normal commercial accuracy of approximately ±1°C throughout the range of the instrument there is a choice between deflection instruments, null-balance bridges and ratiometers. In deflection instruments the galvanometer in the bridge is calibrated so that the out-of-balance current may be read directly as temperature. The current is proportional to the supply voltage of the bridge, and so either the voltage must be stabilised, or voltage compensation must be provided in the galvanometer movement.

In null-balance instruments the bridge circuit is balanced by manual or automatic adjustment of resistance, usually a slide wire, in one or more arms of the bridge.

A ratiometer is a special type of deflection instrument with a double wound coil which moves in a field whose strength is arranged so that direct indication of temperature results.

Compensation for temperature variations in the leads may be provided by either a three-wire or a four-wire system. In the three-wire system two leads are in adjacent arms of a bridge, thus cancelling their changes of resistance, while the third lead carries only the energising current. Such an arrangement is shown in the diagram below. In the four-wire system a lead equivalent to the element leads and subject to the same ambient temperature variations is put in an adjacent arm of the bridge.



Circuit diagram of a three-wire platinum resistance thermometer and bridge.

Determination of Temperature

The relationship between temperature and the resistance of a platinum resistance thermometer, and H. L. Callendar's method of making the necessary calculations, are given in more detail, together with the tables compiled by G. S. Callendar and F. E. Hoare, in a booklet *Platinum for Resistance Thermometry* (12) which was last revised in September 1958. According to the International Temperature Scale, temperature is related to the resistance of a platinum thermometer according to the following formulae:

For the temperature range from 0° to 630.5°C

$$R_t = R_0(1 + At + Bt^2) \qquad (1)$$

and from −183° to 0°C

$$R_t = R_0[1 + At + Bt^2 + C(t - 100)t^3] \qquad (2)$$

where R_t and R_0 are the values for the resistance of the thermometer at the temperature of measurement and at 0°C respectively.

The values of R_0, A and B are determined by calibration at the ice, steam and sulphur (444.6°C) points, and that of C by calibration at the boiling point of oxygen (−182.97°C).

For JMC platinum the values of the coefficients in equation (2) are:

$$A = 3.98 \times 10^{-3}$$
$$B = -5.85 \times 10^{-7}$$
$$C = -4.35 \times 10^{-12}$$

It was first suggested by Callendar that the arithmetical computation could be greatly reduced by rewriting (1) for the range 0–100°C in the form

$$t = \frac{R_t - R_0}{R_{100} - R_0}\, 100 + \delta \left(\frac{t}{100} - 1\right) \frac{t}{100} \qquad (3)$$

where δ is a constant.

The first term in this expression is the "platinum temperature", derived by con-

Properties of JMC Thermopure Platinum	
Specific gravity	**21.40**
Melting point, °C	**1769**
Resistivity, microhm-centimetres at 0°C	**9.81**
Mean temperature coefficient of resistance, (0–100°C) per °C, α	**0.003923**
Callendar correction factor, δ ..	**1.493**
Van Dusen correction factor, β	**0.111**
Thermal conductivity, CGS units	**0.17**
Ultimate tensile strength, tons per square inch (annealed) ..	**9**
Elongation, per cent (annealed) ..	**40**

sidering that the temperature interval between 0° and 100°C can be divided into equal degrees C of temperature by equating temperature to the electrical resistance of a platinum thermometer in this range, and that the relationship can then be extrapolated according to a straight line law. It is denoted by t_{pt}.

Equation (3) may therefore be written

$$t-t_{pt}=\delta\left(\frac{t}{100}-1\right)\frac{t}{100} \qquad (4)$$

The correction from degrees platinum to degrees C is most simply ascertained by the use of the tables compiled by Callendar and Hoare (12).

Equation (3) may also be written

$$t=\frac{1}{\alpha}\left(\frac{R_t}{R_0}-1\right)+\delta\left(\frac{t}{100}-1\right)\frac{t}{100} \qquad (5)$$

where α is the mean temperature coefficient of resistance from 0° to 100°C, i.e.

$$\frac{R_{100}-R_0}{100R_0}$$

The relation between the coefficients in equations (5) and (1) is

$$A=\alpha\left(1+\frac{\delta}{100}\right) \qquad \alpha = A+100B$$

$$B=-\frac{\alpha\delta}{10^4} \qquad \delta=-\frac{10^4B}{A+100B}$$

For temperatures below 0°C the equation (2) above may be written in the Callendar-Van Dusen form

$$t-t_{pt}=\delta\left(\frac{t}{100}-1\right)\frac{t}{100}+\beta\left(\frac{t}{100}-1\right)\left(\frac{t}{100}\right)^3$$

or

$$t=\frac{1}{\alpha}\left(\frac{R_t}{R_0}-1\right)+\delta\left(\frac{t}{100}-1\right)\frac{t}{100}+\beta\left(\frac{t}{100}-1\right)\left(\frac{t}{100}\right)^3$$

The relation between A, B, α and δ is the same as those above mentioned and the other relations are:

$$C=-\frac{\alpha\beta}{10^8} \text{ and } \beta=-\frac{10^8C}{A+100B}$$

Typical Applications

The range of industrial applications of the platinum resistance thermometer, as indicated earlier in this article, is extremely varied and involves the measurement or control of temperatures from the region of −200°C up to 1000°C. Only a relatively few such applications can be described and illustrated here.

In a modern passenger aircraft there may be up to fourteen resistance thermometers. These are required to measure the temperatures of the oil, the fuel, the cabin air, the outside air—for air-speed correction—and the de-icing mats. Base metal thermocouples could be used to measure such temperatures, but would require either control of, or adjustment for, the cold junction temperature, while their low output would necessitate a very sensitive measuring device or some form of amplification. Platinum resistance thermometers fitted with stainless steel sheaths and used in conjunction with ratiometer indicators are therefore preferred.

In power stations resistance thermometers are used, generally with Wheatstone bridges and multi-point indicators, to measure steam, gas and water temperatures.

Two of the illustrations give examples of the wide use of platinum resistance thermometers in the storage, processing and trans-port of food. Other examples are in the storage of fruit in carbon-dioxide, in dock-side grain silos and in refrigerated cargo ships. Ships carrying refrigerated meat or fruit may have nearly a hundred platinum resistance thermometers connected to multi-point indicators, while in the control of space-heating in large buildings such as cinemas a number of instruments will be similarly connected to one indicator.

In the chemical industry—one of the largest users of platinum resistance thermometers—the instruments are used both for precise laboratory measurements and for indication, recording and control in process plants throughout the factory.

A resistance thermometer by Sangamo Weston Limited, to measure air temperature for speed correction, may be seen behind the shield at the end of the spar on the port side of the Bristol Britannia. The spar also carries two ice detectors.

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