

Temperature measurement —

Part 3: Guide to selection and use of industrial resistance thermometers

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Foreword

This Part of BS 1041 has been prepared under the direction of the Industrial-process Measurement and Control Standards Committee. It is a revision of BS 1041-3:1969 which is withdrawn, revision having proved necessary as a result of continuing developments. This revision is intended to provide guidance on the selection and use of resistance thermometers, primarily in the sphere of plant instrumentation but also for scientific and technological use in many other fields.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 16, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

0 Introduction

All materials that conduct electricity exhibit some change of resistance with temperature. However, the magnitude and character of that change depends upon the material used, as does the temperature range over which it may be used. For many years practical thermometers relied upon a small number of pure metals, having positive changes of resistance with temperature. However, in the past few decades semiconductor materials have become available, enabling the production of resistance thermometer sensing resistors possessing much greater variation of resistance with temperature, and with negative or positive characteristics. Standardization of semiconductor elements has not yet been achieved but new fields of application of resistance thermometry have been opened up by their development. However, although a wide variety of metallic and semiconductor resistance thermometer sensors have been developed for special applications, particularly at very low temperatures, this code is concerned only with those which have achieved substantial industrial usage.

In the past, resistance thermometry practice usually favoured the use of null-balance bridges, generally resistive, but sometimes capacitive or inductive. Nowadays, constant current circuits are available enabling resistance thermometer sensors to be used with standard voltage measuring instruments (e.g. digital voltmeters). Also, as a result of recent advances in digital electronics and the use of microprocessors, there are now available a number of digital thermometers which indicate directly in temperature units.

1 Scope

This Part of BS 1041 gives guidance on the selection and use of industrial resistance thermometers incorporating a metallic or semiconductor sensing resistor, which changes in resistance with temperature.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purpose of this Part of BS 1041, the following definitions apply.

2.1

resistance thermometer

a measuring device for ascertaining and exhibiting, in some suitable manner, the temperature of the thermometer sensing resistor. Essentially, it consists of a sensing resistor together with a measuring element and some form of interconnection

2.2

resistance thermometer sensor

a temperature-responsive device consisting of a sensing resistor within a protective sheath, internal connecting wires and external terminals to permit the connection of electrical measuring elements

NOTE 1 Mounting means or connection heads may be included.

NOTE 2 Typical constructions are shown in Figure 1.

2.3

sensing resistor

that part of the resistance thermometer sensor of which the change in resistance is used to measure temperature

2.4

measuring element

that part of the thermometer which responds to the change of resistance of the sensing resistor and enables an evaluation of the temperature of that resistor to be made

2.5

internal connecting wires

that part of the thermometer which provides electrical connection between the sensing resistor and the terminals at the head of the sensors

NOTE Compensating leads may be included.

2.6

external connecting cable

that part of the thermometer which connects the terminals at the head of the sensor to the measuring element

NOTE In some designs of thermometers which are not fitted with terminals, the internal and external connecting wires may be joined together within the head of the thermometer sensor.

2.7

metallic resistance thermometer sensor

a resistance thermometer sensor, the sensing resistor of which is a metallic conductor

2.8

semiconductor resistance thermometer sensor

a resistance thermometer sensor, the sensing resistor of which is a semiconductor

2.9

resistance ratio

the ratio of resistance at a temperature t °C to that at 0 °C (expressed as R_t/R_0)

2.10

padding resistor

a resistor which is sometimes used in conjunction with the sensing resistor to bring the resistance of the thermometer sensor within specified limits

3 Principle of resistance thermometry

The electrical resistance of a material varies with any change in its temperature. In a resistance thermometer sensor, a metallic conductor or a semiconductor material with a large, reproducible and stable change of resistance with temperature is mounted to give mechanical and chemical protection while maintaining good thermal contact with its environment. Electrical connections are provided so that the resistance may be measured. This resistance can be related to temperature once the characteristic has been established.

4 Constructional features of metallic resistance thermometer sensors

Platinum is predominantly used for the sensing resistors of industrial metallic resistance thermometer sensors because its refinement and properties are well established, its temperature/resistance characteristic is reproducible and it can be used up to about 850 °C. Nickel is sometimes used on the grounds of economy or because of its better sensitivity, but its characteristic is less linear. Copper, which has good linearity but sensitivity poorer than nickel, is also sometimes used, but neither of these base metals is normally suitable for sensing resistors which are to be used outside the range – 100 °C to + 180 °C.

In order to maintain long-term stability it is necessary to minimize strain in the sensing resistor during fabrication and subsequent use. It is also desirable that resistance thermometer sensors should be constructed such that:

- a) thermoelectric voltages which may be generated by the use of dissimilar metals cancel each other;
- b) current flowing through them produces insignificant self-heating;
- c) the windings are non-inductive;
- d) they are suitable for use in measuring systems using direct current or alternating current at frequencies up to 500 Hz;
- e) the transmission of heat to and from the sensing resistor by conduction along the sheath, internal wires and insulators is negligible;
- f) the insulation resistance between the sensing resistor (including its internal connecting wires) and the protective sheath is adequate.

The design of a platinum wire-wound industrial sensing resistor necessarily involves a compromise between insensitivity to vibration and stability of characteristic, since to maximize its ability to withstand vibration the wire should be fully encapsulated and cannot therefore be entirely strain-free. (In contrast, thermometers made for use as laboratory standards of the highest accuracy are usually constructed so that the resistance wire is free to expand and contract with the minimum of constraint.) For industrial thermometers where vibration levels are such that it is essential to attach the wire firmly to the former, the wire is usually wound upon a glass or ceramic former, which is then coated with glass or ceramic cement. The coating is selected in an attempt to match the expansion properties of the platinum, but although the thermometer is extremely robust it has somewhat poorer stability than a partially-supported coil. The temperature range over which it can be used does not normally exceed 500 °C.

In the partially-supported coil construction, helical coils of platinum wire are mounted in the bores of a multi-bore alumina tube. The coils are anchored by a small amount of glaze so that while the greater part is free, a small portion of each turn is attached. An alternative method involves embedding the platinum coil in alumina powder to reduce the effects of vibration. By these techniques, thermometers with stabilities of a few hundredths of a degree can be constructed for use over the range – 200 °C to + 850 °C.

Recent years have seen the introduction of a design of metallic resistance thermometer sensor in which the sensing resistor is a film of platinum deposited onto a suitable substrate. Such sensors, which can be produced at a very modest cost, are highly insensitive to vibration and have stabilities similar to those of wire-wound glass-coated detectors over the range from about – 50 °C to + 500 °C. They are particularly suited to applications such as surface temperature measurement and air temperature monitoring. They generally show fast time response, due to the intimate contact of the film with the substrate and the lower mass that needs to be heated.

Constructional methods similar to those described for platinum may be used with other metals, such as copper and nickel. Resistance thermometer sensing resistors of all types can be fabricated in various shapes, limited only by the need to ensure an adequate electrical resistance efficiently insulated. The surface area can be made large in relation to the volume to provide fast response or the sensing resistor can be made compact for measuring temperature at a point. Alternatively, it can be extended over a considerable distance so as to measure an average temperature.

It is sometimes permissible to immerse the sensing resistor directly in the medium of which the temperature is being measured. This method has the advantage that the sensor responds rapidly to temperature changes. Generally, however, some form of protection is necessary. This may be merely a ventilated cover for mechanical protection as in the measurement of static or low-velocity air temperatures, or a completely enclosed and sealed sheath for protection against corrosive or electrically-conductive fluids, high pressures or abrasive media.

Where total enclosure of the sensing resistor is necessary, special consideration should be given to the thermal conductance between the sheath and the sensor and precautions will be needed to minimize errors caused by conduction of heat along the sheath as well as along the internal connecting wires. The time of response and the self-heating of the sensing resistor may also be significant, especially if it is situated inside a heavy thermowell, or is being used to measure static gas temperatures.

5 Constructional features of semiconductor resistance thermometer sensors

The temperature-sensitive material is usually a sintered metal oxide and is often encapsulated in glass. As no support is required and as the resistivity is much higher than that of any metal used in resistance thermometry the sensing resistors can be extremely small. Typically a bead, 0.25 mm to 0.5 mm diameter, is thinly glazed, and supported by its leads. To provide further chemical and mechanical protection and electrical insulation it may be sealed in the tip of the glass probe.

Sensing resistors in rod or disc form are commonly available, thin discs being particularly suitable for surface temperature measurement. However, generally, semiconductor sensors are not appropriate for use in averaging temperature measurement.

6 Characteristics of resistance thermometers

6.1 General

Characteristics which are common to both metallic and semiconductor resistance thermometer sensors include the following.

- a) An external power supply is always required to energize the resistance thermometer sensor. Operation may be by direct current or by alternating current at frequencies usually not in excess of 500 Hz.
- b) The energy dissipated in the sensing resistor by the current that passes through it causes a rise of temperature of the resistor above its surroundings. The magnitude of the temperature rise depends upon the design and construction of the sensing resistor, its mounting and the medium in which it is used, as well as upon the measuring current. For example, an unmounted resistor which has a self-heating effect of $< 0.01\text{ }^{\circ}\text{C}/(\text{m W})$ when immersed in a stirred water bath, may show an effect between 20 and 40 times greater when used in unstirred air. In practice, the energy dissipated is limited so as to prevent significant errors in temperature measurement, while still maintaining a relatively high output signal.
- c) Thermal response time is limited by the need to protect and insulate the temperature-sensitive material. Variations in construction lead to widely differing response times. A response time of 0.5 s or less can be achieved with some sealed sensors.
- d) It is possible to make circuits intrinsically safe.
- e) The accuracy of the measuring element can be checked by substituting precision temperature-stable resistors for the sensing resistor.
- f) Measuring circuits can be used in which no compensation is necessary for changes in ambient temperature.

6.2 Metallic resistance thermometer sensors

Metallic resistance thermometer sensing resistors capable of providing accurate, reliable and reproducible temperature measurement in the range from about $-260\text{ }^{\circ}\text{C}$ to $+850\text{ }^{\circ}\text{C}$ (or higher) are available, but it should be emphasized that only with more specialized resistance thermometers can temperatures below $-200\text{ }^{\circ}\text{C}$ or above $600\text{ }^{\circ}\text{C}$ be measured. Metallic sensing resistors possess the following special characteristics.

- a) The temperature coefficient of resistance is always positive.