

BRITISH STANDARD 1041 : Part 4 : 1966

**CODE FOR
TEMPERATURE
MEASUREMENT**

Part 4. Thermocouples

BRITISH STANDARDS INSTITUTION

Gr 7

CODE FOR TEMPERATURE MEASUREMENT

Part 4. Thermocouples

B.S. 1041 : Part 4 : 1966

BRITISH STANDARDS INSTITUTION

Incorporated by Royal Charter

2 PARK STREET LONDON W1A 2BS

Telex: 266933

Telephone: 01 - 629 9000

UDC 536.51/.55 + 536.532 : 621.362

 **Documents**
Document Sharing Hub

B.S. 1041 : Part 4 : 1966

THIS BRITISH STANDARD, having been approved by the Instrument Industry Standards Committee and endorsed by the Chairman of the Engineering Divisional Council, was published under the authority of the General Council on 1st March, 1966.

First published, January, 1943.

First revision (Part 4), March, 1966.

The Institution desires to call attention to the fact that this British Standard does not purport to include all the necessary provisions of a contract.

In order to keep abreast of progress in the industries concerned, British Standards are subject to periodical review. Suggestions for improvements will be recorded and in due course brought to the notice of the committees charged with the revision of the standards to which they refer.

A complete list of British Standards, numbering over 4000, fully indexed and with a note of the contents of each, will be found in the British Standards Yearbook. The B.S. Yearbook may be consulted in many public libraries and similar institutions.

This standard makes reference to the following British Standard:

B.S. 1041. Code for temperature measurement.

British Standards are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users of British Standards should ascertain that they are in possession of the latest amendments or editions.

The following B.S.I. references relate to the work on this standard:
Committee references INE/4, INE/4/3
Draft for comment D 63/3819

CONTENTS

	Page
Co-operating organizations	4
Foreword	5

CODE

1. Scope	6
2. Principle of the method	6
3. Characteristics of the method	7
4. Materials for thermocouples	8
5. Calibration of thermocouples	8
6. Operating features	11
7. Connecting circuits	20

APPENDICES

A. Instruments for use with thermocouples	22
A1. Direct-deflection instruments	22
A2. Comparison of direct-deflection instruments with potentiometric instruments	27
A3. Potentiometric instruments	27
A4. Data processing and logging systems	32
A5. Broken thermocouple alarm and safety systems	33
B. Thermocouple characteristics	35

CO-OPERATING ORGANIZATIONS

The Instrument Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

- British Clock and Watch Manufacturers' Association
- *British Electrical and Allied Manufacturers' Association
- *British Industrial Measuring and Control Apparatus Manufacturers' Association
- *British Iron and Steel Federation
- British Nautical Instrument Trade Association
- British Railways Board
- British Scientific Instrument Research Association
- Council of British Manufacturers of Petroleum Equipment
- Electrical Research Association
- *Electricity Council, the Generating Board and the Area Boards in England and Wales
- Electronic Engineering Association
- *Engineering Equipment Users' Association
- Gauge and Tool Makers' Association
- Institution of Chemical Engineers
- *Institution of Electrical Engineers
- Institution of Heating and Ventilating Engineers
- *Institution of Mechanical Engineers
- Institution of Production Engineers
- Iron and Steel Institute
- Meteorological Office
- *Ministry of Defence, Army Department
- Ministry of Health
- National Coal Board
- *National Physical Laboratory (Ministry of Technology)
- *Oil Companies Materials Association
- *Scientific Instrument Manufacturers' Association
- Society of Instrument Technology
- Water-tube Boilermakers' Association
- Water Resources Board

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this standard:

- British Coal Utilisation Research Association
- Engineering Industries Association
- Gas Council
- Institute of Physics and the Physical Society
- Ministry of Aviation
- Ministry of Power
- Society of Chemical Industry
- Manufacturers of thermocouple wire

BRITISH STANDARD

CODE FOR TEMPERATURE MEASUREMENT

Part 4. Thermocouples

FOREWORD

The first edition of this British Standard was issued in 1943 for the convenience of engineers responsible for the control and testing of heat-using plant. At that time it was regarded by the drafting committee as an essay which was to be improved and expanded when the industrial users to whom it was addressed had had an opportunity to assess its merits and shortcomings.

In revising the standard, the committee has been influenced by the knowledge that the first edition was used not only in the sphere of plant instrumentation but also by scientists and technologists in many other applications of thermometry.

The parts comprising this present revision are being prepared and issued separately in order to avoid the delay of a publication postponed until all the parts are ready.

Not the least important task in temperature measurement is to decide precisely what information is required, what temperature measurements are essential for the purpose in view and what are non-essential but of value for the interpretation of the results.

The accuracy to be aimed at in the temperature measurements must necessarily be limited by the errors inherent in the measurements themselves, but these errors may well be less than the tolerance for a particular process. A realistic estimate should therefore be made of the magnitude of the error which would be significant, in order to avoid the use of an unnecessarily accurate, and hence expensive, method.

The general scheme of thermometric operations having been decided, the type of instrument most appropriate to each determination should be selected. The selection should be governed not only by considerations of range, accuracy, speed of response and convenience but also by any special conditions which may obtain, such as the presence of corrosive liquids or gases, the possibility of chemical reactions or the effect of catalytic phenomena on the measuring devices, and similar effects. The exact location of the thermometric instruments should be decided; for this it will be necessary to give weight to such factors as ease of access and the degree of accuracy obtainable at a given point. To this end a careful survey of the conditions of heat flow should be made. The possible effects of mechanical, thermal and electrical disturbances in the environment are pertinent factors, especially when long cables run from the sensitive element to the measuring instrument.

B.S. 1041 : Part 4 : 1966

This standard forms one of a series of British Standards relating to temperature measurement which includes the following:

- B.S. 1041. Code for temperature measurement.
- B.S. 1794. Chart ranges for temperature recording instruments.
- B.S. 1826. Reference tables for platinum/rhodium *v* platinum thermocouples.
- B.S. 1827. Reference tables for nickel/chromium *v* nickel/aluminium thermocouples.
- B.S. 1828. Reference tables for copper *v* constantan thermocouples.
- B.S. 1829. Reference tables for iron *v* constantan thermocouples.
- B.S. 1843. Colour code for twin compensating cables for thermocouples.
- B.S. 1904. Industrial platinum resistance thermometer elements.
- B.S. 2082. Code for disappearing-filament optical pyrometers.
- B.S. 2765. Dimensioning system and terminology for industrial temperature-detecting elements and pockets.
- B.S. 3166. Thermographs (liquid-filled and vapour pressure types) for use within the temperature range -20°F to 220°F (-30°C to 105°C).
- B.S. 3231. Thermographs (bimetallic type) for air temperatures within the range 0°F to 140°F (-20°C to 60°C).
- B.S. 3273. Distant indicating thermometers for ships' refrigerated cargo spaces.

CODE

SCOPE

1. This British Standard is intended to give guidance in the selection of the most appropriate thermocouple method of temperature measurement in any particular case, to indicate the sources of error and the inherent limitations, and to formulate the precautions which should be observed.

Given in Appendix A is a survey of various types of instruments for use with thermocouples together with a short description of each type.

A table is included as Appendix B in which a summary is made of the operating characteristics of the thermocouples described in the standard.

PRINCIPLE OF THE METHOD

2. A thermocouple consists essentially of two dissimilar conductors which may be pure metal, alloys or non-metals. At one end the two conductors are formed into a junction at which the conductors are in good electrical and thermal contact. This junction is known as the measuring junction. The other ends of the conductors are made available for connection to the terminals of an electromotive force measuring system. This end is known as the reference junction. If the conductors are insulated from each other (except at the measuring junction)

and if a temperature difference exists between the measuring and reference junctions an electromotive force will be developed. The magnitude of the electromotive force can be determined by the measuring system to which the reference junction is connected, and will depend on a number of factors which are discussed in the ensuing clauses. It follows that the thermocouple can measure only the difference of temperature between its measuring junction and its reference junction. If it is attached to an instrument which displays the temperature of the measuring junction, it is necessary to provide means of measuring the temperature of the reference junction and then add this to the measure of temperature derived from the thermocouple system. It should be borne in mind that the error of the system includes all the errors of the component parts.

The two conductors constituting the thermocouple must be so chosen that any changes caused by the physical and chemical conditions to which they are exposed shall not result in any appreciable change in the calibration. The calibration may change as a result of oxidation, reduction, other chemical attack or the preferential evaporation of constituents of an alloy. As the reference junction is often installed remotely from the measuring junction, it is frequently inconvenient or unduly expensive to make the entire conductors between the two junctions of the thermocouple materials. Compensating leads are employed made of a pair of materials with an electromotive force/temperature relationship similar to that of the thermocouple over a restricted range of temperatures (say 0–70°C). For the compensation to be effective the junction between thermocouple conductors and compensating conductors must be within this range of temperature.

CHARACTERISTICS OF THE METHOD

3. Thermocouples can be used over a very wide range from below 0°C to 2600°C and provide accurate, reliable and reproducible temperature measurements. The characteristics of the thermocouple method may be listed as follows:

a. Many thermocouple combinations exist and each has an optimum temperature range. Selections may be made from the variety of base and rare metal types to meet the requirements of most operating conditions.

b. Most thermocouple materials are readily available with electromotive force/temperature characteristics guaranteed to within stated tolerances.

c. Thermocouples may be made from very fine wires and hence are of low thermal capacity. They can therefore respond rapidly to fluctuating temperatures.

d. No external electrical supply is required except where highly accurate potentiometric methods of electromotive force measurement must be used.

e. Sensitivity of response may be increased by using several thermocouples in series.

f. Measuring junctions may be easily made by the user and thermocouples may be easily installed and maintained.

g. Usually only simple methods of measuring the electromotive force are required.

h. The thermocouple method requires the use of a reference junction and special precautions may have to be adopted to compensate for variations in the temperature of this junction.

MATERIALS FOR THERMOCOUPLES

4. The materials which, up to the present, have been found suitable for use in thermocouples are limited to a small number of metals and alloys. The materials most widely used are shown in Table 1 and may be divided into two groups: (*a*) Base-metals, (*b*) Rare-metals. Broadly speaking, for temperatures in the range from 1100 C to 1800 C, rare-metal thermocouples are most appropriate. In both groups the low temperature limit of working is usually decided by the limiting minimum electromotive-force which can be employed with measuring instruments. In this respect base-metal thermocouples have the advantage in general of developing relatively large electromotive forces. Where the temperatures to be measured approach the upper safe limit for the use of thermocouples, other methods of temperature measurement, such as those which make use of the radiation from the hot body, may be more suitable.

CALIBRATION OF THERMOCOUPLES

5. The calibration of all thermocouples should be based upon the International Practical Scale of Temperature, which is defined in 'Units and Standards of Measurement No. IV': National Physical Laboratory, published by H.M.S.O. 1962.

With base-metal thermocouples conditions of manufacture frequently make it inevitable that some elements other than the main constituents will be present in a sensible proportion, and the existence of these has to be accepted. When base-metal thermocouples, used within their normal useful range, are required to measure temperatures to closer tolerances than shown in Table 2, each individual thermocouple should be calibrated.

Rare-metal thermocouples can be manufactured to have the requisite composition and degree of purity to conform to the tolerances indicated in Table 2. When high accuracy is desired, the individual calibration advised in the above paragraph should be carried out.

TABLE 1. COMPOSITIONS AND OPERATING TEMPERATURES OF THERMOCOUPLES

1	2	3	4	5
Thermocouple (See Note 1)	Nominal composition	Operating temperatures °C		Relevant B.S. Reference Tables
		Normal range for continuous use	Maximum 'Spot' readings	
<i>Base-metals</i> Copper v constantan Iron v constantan	Cu v Cu-Ni (40/45% Ni) Fe v Cu-Ni (40/45% Ni)	-- 250 to 400 -- 200 to 850 See Note 2	500 1100	B.S. 1828 B.S. 1829
Nickel/chromium v constantan	Ni 90%, Cr 10% v Cu-Ni (40/45% Ni)	-- 200 to 850 See Note 2	1100	Refer to manufacturer's data B.S. 1827
Nickel/chromium v nickel/aluminium	Ni 90%, Cr 10% v Ni 95%, balance Al, Si, Mn.	-- 200 to 1100 See Note 2	1300	
Tungsten/rhenium v tungsten/rhenium (See Note 4)	W 95% Re 5% v W 74% Re 26%	0 to 2300 See Note 2	2600	
Tungsten v molybdenum (See Notes 4 and 5)	W v Mo	1250 to 2600	2600	Refer to manufacturer's data
<i>Rare-metals</i> Platinum/rhodium v platinum Platinum/rhodium v platinum Platinum/rhodium v platinum/rhodium Platinum/rhodium v platinum/rhodium Platinum/rhodium v platinum/rhodium	Pt 90% Rh 10% v Pt 100% Pt 87% Rh 13% v Pt 100% Pt 80% Rh 20% v Pt 95% Rh 5% Pt 70% Rh 30% v Pt 94% Rh 6% Pt 60% Rh 40% v Pt 80% Rh 20%	0 to 1400 0 to 1400 0 to 1500 0 to 1500 1000 to 1600 See Note 6	1650 1650 1700 1700 1800 2100	
Rhodium/iridium v iridium	See Note 3	0 to 2000	2100	

NOTE 1. The first-named element in Columns 1 and 2 is the positive element of the combination.

NOTE 2. For this type of thermocouple the maximum continuous operating temperatures should only be related to wires of 0.064 in diameter and larger.

NOTE 3. In using these thermocouples the actual operating conditions should be borne in mind and the guidance of the manufacturer sought with regard to suitable compositions for particular conditions of use.

NOTE 4. These thermocouples should only be used in non-oxidising atmospheres.

NOTE 5. These thermocouples should not be used below 1250°C because of the electromotive force reversal.

NOTE 6. These thermocouples are not generally used below 1000°C due to their low sensitivity.

The reference table or graphical representation of the electromotive-force/temperature relationship for any one class of thermocouple represents the mean values for a series of thermocouples of that class and thermocouples supplied should conform to the reference tables within the tolerances indicated in the table below:

TABLE 2. THERMOCOUPLE TOLERANCES

Type of thermocouple	Tolerance	Temperature range °C
*Copper <i>v</i> constantan	$\pm 1 \text{ degC}$	0 - 100
	$\pm 1 \%$	100 - 400
*Iron <i>v</i> constantan	$\pm 3 \text{ degC}$	0 - 300
	$\pm 1 \%$	300 - 850
*Nickel/chromium <i>v</i> constantan	$\pm 3 \text{ degC}$	0 - 400
	$\pm 0.75 \%$	400 - 850
*Nickel/chromium <i>v</i> nickel/aluminium	$\pm 3 \text{ degC}$	0 - 400
	$\pm 0.75 \%$	400-1 100
Tungsten/rhenium <i>v</i> tungsten/rhenium	Tolerances should be agreed between user and manufacturer	
Tungsten <i>v</i> molybdenum	$\pm 1 \text{ degC}$	0-1 100
Platinum/rhodium <i>v</i> platinum group	$\pm 2 \text{ degC}$	1 100-1 400
	$\pm 3 \text{ degC}$	above 1 400
Platinum/rhodium <i>v</i> platinum/rhodium group	$\pm 3 \text{ degC}$	0-1 100
	$\pm 4 \text{ degC}$	1 100-1 550
Rhodium/iridium <i>v</i> iridium	Tolerances should be agreed between user and manufacturer	

As the presence of mechanical stress may cause variation in its characteristics, care should be taken to avoid stressing the wire in preparing a thermocouple. In the case of a rare-metal thermocouple which has already been in service, re-annealing in air, preferably at a temperature at least as high as it will experience in service, may drive off or oxidize any impurities which may have been absorbed.

* It should be noted that these thermocouples can be used at temperatures below 0°C but in these cases the tolerances are usually the subject of agreement between user and manufacturer. Where the thermocouple is to be used below 0°C a calibration at the boiling point of oxygen should be made.

The calibration of thermocouples may be verified at one temperature which is near the average measured in service. In the case of a test at the freezing point of a standard substance, precautions must be taken to avoid errors due to insufficient mass of the test substance, to insufficient immersion, particularly if a sheath is used, and to close proximity to the side or bottom of the vessel containing the standard substance. Care should be taken to ensure that the two junctions of the extension leads and thermocouple should be at the same temperature. For fuller details of a method of test refer to National Physical Laboratory's Notes on Applied Science No. 12, 'Calibration of temperature measurement instruments'.

If thermocouple wires become inhomogeneous the electromotive force developed will be influenced by the location of the temperature gradient with respect to the region of inhomogeneity. Thus the output of the thermocouple will vary with depth of immersion. If a thermocouple has been in service in one position for some time and a condition of inhomogeneity may have arisen it is best when possible to check it *in situ*. Such a test can be arranged to include the whole installation of the thermocouple compensating leads and measuring instrument. The freezing point test referred to above may also be used for such an overall test provided it is possible to withdraw the thermocouple from its service position and to conduct the test without disconnecting or otherwise altering the installation. Errors due to inhomogeneity in the thermocouple will not be revealed by such a test unless the test conditions for depth of immersion and temperature gradient are identical with the service conditions.

It should be noted that the electromotive force characteristic of a thermocouple may change appreciably before there is any sign of mechanical weakness and for this reason it is important to recalibrate frequently and the need for and importance of this precaution increases with approach to the maximum temperatures given in Table 1.

OPERATING FEATURES

6.1. Dimensions. To reduce the effects of thermal conduction along the elements from the measuring junction to other parts of the thermocouple system, and also to reduce the effects of radiation and the time taken to attain thermal equilibrium, the cross-section of the conductors should be small; on the other hand, in order to increase mechanical strength and life the cross-section should be large. In practice a compromise in the case of base-metal thermocouples is accepted. Since rare-metal thermocouples have some inherent durability due to their being highly resistant to oxidation, their relatively high cost dictates the choice of a small cross-section and 0.020 in diameter wire is normally used.

The length of the thermocouple itself, apart from any compensating leads, should allow of immersion in the heated zone to a sufficient depth to eliminate errors due to conduction losses and also to place the point of attachment (to