Temperature

In 1848, Sir William Thomson (Lord Kelvin) stated the zero principle of dynamics. This principle enabled him to define thermodynamic temperature and to establish an objective method of measuring it.

When two systems are each in thermal equilibrium with a third, they are in thermal equilibrium with each other. This equilibrium is expressed by their equal temperatures. If a conventional value is ascribed to the temperature of a system in a given physical state, other temperatures can be determined by thermodynamic measures.

In 1961, the General Conference on Weights and Measures chose as the standard unit of thermodynamic temperature the Kelvin (K), defined as the degree on the thermodynamic scale of absolute temperatures at which the triple point of water is 273.16K (the equivalent of 0°C). At this temperature ice, water and water vapour can co-exist in equilibrium.

According to this convention the freezing and boiling points of water under atmospheric pressure are respectively 273.15K and 373.15K. The temperature interval measured by one Kelvin is equal to that which measures 1°C.

Without the facilities of highly specialised laboratories, it is extremely difficult to use thermodynamic thermometers (gas and radiation types) and other phenomena are utilised for practical convenience:

- i) Change in electrical resistance with temperature in metals
- ii) thermoelectric activity (e.m.f. produced by thermocouples)

On this basis, resistance thermometers and thermocouples have been developed. In order to define the relationship between temperature and the electrical properties of such sensors, they have to be measured and compared at given temperature values. Temperature scales were devised to this end based on “fixed points”, temperatures at which pure elements change their physical states (solid/liquid/gas). Interpolations between these points are made by highly precise thermometers for specified temperature ranges. The international temperature scale -ITS 90 provides the current, practical reference.

Introduction

THE NEW LABFACILITY TEMPERATURE HANDBOOK

A comprehensive reference text and user guide for anyone involved in temperature measurement and control

The new Labfacility Temperature Handbook is a budget priced comprehensive, up to date reference text for users of thermocouples, PRTs and thermistors and associated instrumentation. Detailed enough for engineers and scientists, it is also suitable for technicians and students. Written with practical bias, the handbook contains considerable reference data and basic theory and is therefore of great value as a training aid for those entering the field of temperature measurement and control.

The handy A5 size book contains 139 pages, 40 of them being reference data and uses 65 illustrations. The broad scope of the handbook includes detailed temperature sensor guidance, sensor theory and practice and comprehensive applications guidance. Additional chapters describe temperature control, transmitters, instrumentation and data acquisition and a 40 page reference section carries a wealth of data on thermocouple and platinum resistance thermometry.

This handbook is designed to be of particular value to those technicians and engineers involved with electrical temperature measurement and control. The emphasis is on practical aspects but the basic theory and applications aspects will be of particular interest to students and apprentices.

Information provided in this publication is intended as general guidance and not necessarily deemed definitive. Every effort has been made to ensure the accuracy of information presented but the reader should refer to manufacturer/supplier data and relevant published standards when procuring or using any sensors, materials or equipment.

Specifications and data included in this handbook may be subject to change

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1. TEMPERATURE MEASUREMENT USING ELECTRICAL TECHNIQUES

Thermocouples Resistance Thermometers and Thermistors are in effect electrical temperature transducers and not direct-indicating thermometers such as mercury-in-glass devices.

In the majority of industrial and laboratory processes, the measurement point is usually remote from the indicating or controlling instrument. This may be due to necessity (e.g. an adverse environment) or convenience (e.g. centralised data acquisition). Devices are required which convert temperature into another form of signal, usually electrical and most commonly thermocouples, resistance thermometers and thermistors.

Alternative indirect techniques for sensing and measuring temperature include optical pyrometry, other non-contact (infra red), fibre-optic and quartz oscillation systems.

The use of thermocouples, resistance thermometers and thermistors requires some form of physical contact with the medium. Such contact can be immersion or surface depending on the sensor construction and the application.

THERMOCOUPLES RESISTANCE THERMOMETERS AND THERMISTORS

Thermocouples essentially comprise a thermoelement (a junction of two specified dissimilar metals) and an appropriate two wire extension lead. A thermocouple operates on the basis of the junction located in the process producing a small voltage which increases with temperature. It does so on a reasonably stable and repeatable basis.

Resistance Thermometers utilise a precision resistor, the Ohms value of which increases with temperature (in the case of a positive temperature coefficient). Such variations are very stable and precisely repeatable.

Thermistors are an alternative group of temperature sensors which display a large value of temperature coefficient of resistance (usually negative, sometimes positive). They provide high sensitivity over a limited range

In practical terms, the alternative types of assembly utilise similar (in some case identical) construction but must be used in different ways depending on the application.

Comparison of Sensor Types

	Platinum Resistance Thermometer	Thermocouple	Thermistor
Sensor	Platinum-wire wound or flat-film resistor	Thermoelement, two dissimilar metals/ alloys	Ceramic (metal oxides)
Accuracy (typical values)	0.1 to 1.0°C	0.5 to 5.0°C	0.1 to 1.5°C
Long term Stability	Excellent	Variable, Prone to ageing	Good
Temperature range	-200 to 650°C	-200 to1750°C	-100 to 300°C
Thermal response	Wirewound – slow Film – faster 1-50 secs typical	Sheathed – slow Exposed tip – fast 0.1 to 10 secs typical	generally fast 0.05 to 2.5 secs typical
Excitation	Constant current required	None	None
Characteristic	PTC resistance	Thermovoltage	NTC resistance (some are PTC)
Linearity	Fairly linear	Most types non-linear	Exponential
Lead resistance effect	3 & 4 wire – low 2 wire – high	Short cable runs satisfactory	Low
Electrical "pick-up"	Rarely susceptible	susceptible	Not susceptible
Interface	Bridge 2,3 or 4 wire	Potentiometric input. Cold junction compensation required	2 wire resistance
Vibration effects/ shock	wirewound – not suitable Film – good	Mineral insulated types suitable	Suitable
Output/ characteristic	approx. 0.4 Ω/°C	From 10μV/°C to to 40μV/°C depending on type	-4% / °C
Extension Leads	Copper	Compensating cable	Copper
Cost	Wirewound – more expensive Film – cheaper	Relatively low cost	Inexpensive to moderate

Comments and values shown in this chart are generalised and nominal. They are not intended to be definitive but are stated for general guidance. The information given shows average application experience, but some of the considerations can be modified by special design or selection.

These alternative temperature sensors are explained in depth in chapters 2 ,3 and 4.