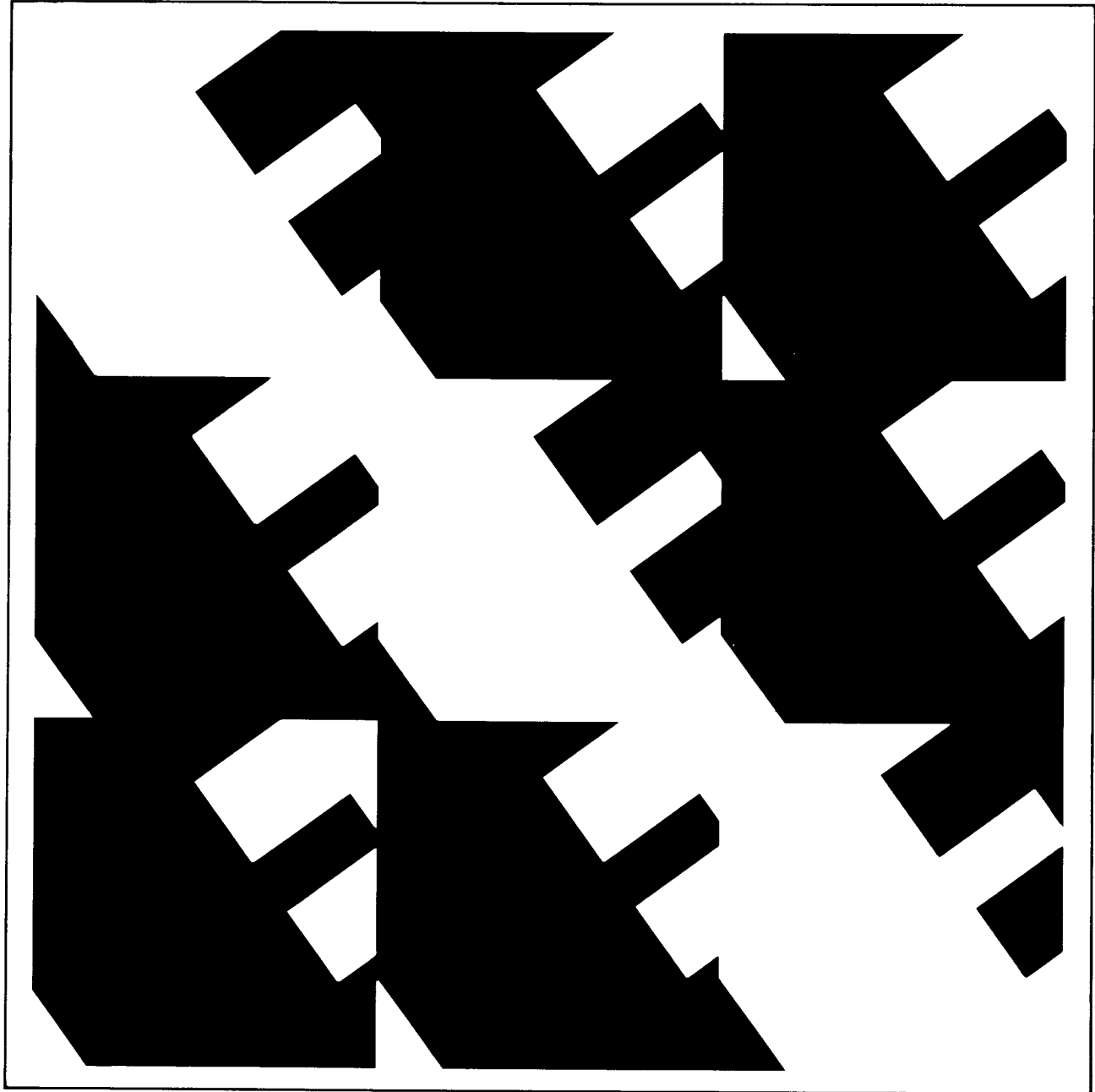


IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus

IEEE Std 119-1974



Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA

January 20, 1975

SH11197

IEEE
Std 119-1974
(Revision of
IEEE Std 119-1966)

IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus

Sponsor
**Power System Instrumentation and Measurements Committee
of the
IEEE Power Engineering Society**

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Foreword

(This foreword is not a part of IEEE Std 119-1974, General Principles of Temperature Measurement as Applied to Electrical Apparatus.)

In the preparation of this document the subcommittee made free use of the American Society of Mechanical Engineers publication PTC 19.3-1974, Part 3, Temperature Measurement, Instruments and Apparatus, and of several publications of the National Bureau of Standards. Portions of the texts and many of the figures have been used with only minor changes. The subcommittee is deeply appreciative of the permission granted by these organizations for this use of their publications.

Sections 4.2 and 4.3 are largely abstracted from corresponding sections of the ASME publication and the user with more than a general interest in these areas should consult that publication for a comprehensive discussion. The ASME publication also contains somewhat more extended coverage of the areas dealt with in Sections 4.4 and 4.5.

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IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus

1. Scope

The purpose of this document is to provide guidelines for the application of temperature-measurement techniques in measuring the operating temperature and temperature rise of electrical machines, instruments, and apparatus in common use. The guidelines are limited to measurement of temperatures below 500°C; however, some measurement techniques described herein are capable of measuring temperatures above 500°C, and these may be used at the higher temperatures after the validity and safety of the technique for the temperature involved have been confirmed. This recommended practice does not define permissible temperature rise or corrections since they must form a part of the standard for the particular apparatus involved. Should contradiction between guidelines stated herein and those in a specific apparatus test procedure or standard exist, the specific apparatus publication will govern.

Guidance for the selection of temperature limits in the rating of electrical apparatus is provided in IEEE Std 1-1969, General Principles for Temperature Limits in the Rating of Electric Equipment.

2. Definitions

bimetallic thermometer. A temperature-measuring instrument comprising an indicating pointer and appropriate scale in a protective case and a bulb having a temperature-sensitive bimetallic element. The bimetallic element is composed of two or more metals mechanically associated in such a way that relative expansion of the metals due to temperature change produces motion. (See SAMA, PMC-4-1, Bimetallic Thermometers, 2nd ed.)

Bourdon. A closed and flattened tube formed in a spiral, helix, or arc, which changes in

shape when internal pressure changes are applied.

NOTE: Bourdon tube, or simply Bourdon, has at times been used more restrictively to mean only the C-shaped member invented by Bourdon.

embedded temperature detector. An element, usually a resistance thermometer or thermocouple, built into apparatus for the purpose of measuring temperature. (Examination or replacement of an embedded detector after the apparatus is placed in service is usually not feasible.) (See IEEE Std 100-1972, Dictionary of Electrical and Electronics Terms (ANSI C42.100-1972).)

filled-system thermometer. An all-metal assembly consisting of a bulb, capillary tube, and Bourdon tube (see note under Bourdon) (bellows and diaphragms are also used) containing a temperature-responsive fill. A mechanical device associated with the Bourdon is designed to provide an indication or record of temperature. See Fig 10.

infrared radiation thermometer. An optical system that accepts electromagnetic radiation in the infrared portion of the spectrum and either concentrates it on a temperature-sensitive element, which in turn activates an indicating device, or transforms it into radiation in the visible spectrum.

liquid-in-glass thermometer. A thin-walled glass bulb attached to a glass capillary stem closed at the opposite end, with the bulb and a portion of the stem filled with an expansive liquid, the remaining part of the stem being filled with the vapor of the liquid or a mixture of this vapor and an inert gas. Associated with the stem is a scale in temperature degrees so arranged that when calibrated the reading corresponding to the end of the liquid column indicates the temperature of the bulb.

resistance thermometer. An electric thermometer that operates by measuring the electric resistance of a resistor, the resistance of which is a known function of its temperature.

The temperature-responsive element is usually called a resistance temperature detector. (The resistance thermometer is also frequently used to designate the sensor and its enclosing bulb alone, for example, as in platinum thermometer, copper-constantan thermometer, etc.) (See IEEE Std 100-1972.)

response time. The time required for the indication of a thermometer, which has been subjected to an essentially instantaneous change in temperature, to traverse 63 percent of the temperature interval involved. Following such a temperature change the indication of the thermometer may be expected to traverse 99 percent of the temperature interval in a period ranging from 5 to 8 time constants so defined, depending on the details of its construction.

sensor. That portion of a temperature-measuring system that responds to the temperature being measured.

thermistor. An electron device that makes use of the change of resistivity of a semiconductor with change in temperature. (See IEEE Std 100-1972.)

thermocouple. A pair of dissimilar conductors so joined at two points that an EMF (electromotive force) is developed by the thermoelectric effects when the junctions are at different temperatures. (See IEEE Std 100-1972.)

thermocouple extension wire. A pair of wires having such EMF-temperature characteristics relative to the thermocouple with which the wires are intended to be used that, when properly connected to the thermocouple, the reference junction is in effect transferred to the other end of the wires. [See ANSI C96.1-1964 (R1969), Temperature Measurement Thermocouples.]

thermocouple leads. A pair of electrical conductors that connect the thermocouple to the EMF measuring device. One or both leads may be simply extensions of the thermoelements themselves or both may be of copper, dependent on the thermoelements in use and upon the physical location of the reference junction or junctions relative to the measuring device.

thermocouple thermometer. A temperature-measuring instrument comprising a device for measuring EMF, a sensing element called a thermocouple that produces an EMF of magnitude directly related to the temperature difference between its junctions, and electrical conductors for operatively connecting the two.

thermometer. An instrument for determining the temperature of a body or space.

thermopile. A group of thermocouples connected in series aiding. (See IEEE Std 100-1972.)

3. General

3.1 Temperature Scales. By international agreement, the Kelvin scale is now accepted as the absolute thermodynamic scale. Because of the difficulties encountered in the practical realization of the Kelvin scale, a practical working scale, the IPTS-68 (International Practical Temperature Scale of 1968) is used throughout the world in scientific and industrial laboratories. In the range of temperatures pertinent to this guide, the IPTS-68 is defined by four fixed points: the normal boiling point of oxygen at -182.962°C , the triple point of water at $+0.01^{\circ}\text{C}$, the normal boiling point of water at 100°C , and the normal freezing point of zinc at 419.58°C . Temperatures in the range -259.34 to 630.74°C at other than these fixed points are defined in terms of a standard platinum resistance thermometer calibrated at these and other fixed points and using a specified equation for interpolation.

Temperatures on the IPTS-68 are expressed in degrees Celsius. Thermometers graduated on the Fahrenheit scale are calibrated with reference to the IPTS-68 using the following conversion formula: temperature in degrees Fahrenheit = $9/5$ (temperature in degrees Celsius) + 32.

3.2 Temperature-Measuring Techniques. Temperature measurements are made for a variety of purposes. Accurate determination of the temperature of a component to a small fraction of a degree may be required, or determining the temperature to within a degree or

two may satisfy the need. The accurate determination of temperature in most cases requires carefully selected sophisticated equipment, carefully controlled sensor installation, and operation by trained technical personnel. This is expensive and for most purposes is not necessary. The most economical method that will supply information of the required accuracy should be adopted.

When a technique for determining the temperature of electrical apparatus is being selected, several factors must be considered.

- (1) Accuracy of the measurement required
- (2) Physical characteristics of the apparatus or component to be monitored (solid, liquid, gas, physical shape, size, etc)
- (3) Accessibility of the part to be monitored
- (4) Permanency of instrumentation to be installed (a short-term study or life-of-the-equipment installation)
- (5) Range of temperatures to be monitored
- (6) Location of readout device, local or remote
- (7) Electrical potential of component being monitored

The fundamental methods of temperature determination and their basic characteristics are given in Table 1. Specific directions and precautions in the use of these instruments are given in subsequent sections of this guide.

Temperature-measuring devices and techniques such as the magnetic, acoustic, and quartz thermometers that have not yet found application within the scope of this standard are not further discussed. (See [84] through [86].¹)

Recommendations of specific techniques for typical applications are presented in Table 2.

3.3 Temperature Data Acquisition Systems. Thermocouple and resistance thermometers lend themselves to use where temperatures at several locations are to be monitored essentially simultaneously and over extended periods of time. Complete data-logging systems are commercially available for handling inputs from a few to several hundred sensors. The block diagram of a typical thermocouple system is shown in Fig 1.

¹ Numbers in brackets correspond to those in Section 9, Bibliography.

3.4 Installation. Where the sensor is immersed in the material whose temperature is to be measured, it obviously should be so located as to acquire and maintain as nearly as possible the temperature of the material. If the possibility of stratification, stagnation, or gradients exists, care must be exercised to choose a sufficient number of elements and to locate and install them properly, according to the requirements of the measurement to be made. Wherever practical, the sensor should be in direct contact with the medium being monitored rather than separated from it by a wall such as exists in a thermometer well. As nearly as possible the conditions of use of the thermometer with respect to insertion or immersion of the sensor and the arrangement of the leads or capillary should reproduce the conditions extant during its calibration.

In the measurement of surface temperature, the extent of insertion of the sensor will obviously be limited by the thickness of the material whose temperature is being measured. Thermocouples are generally used for this purpose. To aid in bringing the measuring junction to the temperature of the material surface, the junction should be peened or brazed into position when possible and a portion of the insulated thermocouple leads should be in intimate contact with the material surface. Care must, of course, be taken to insure that such an electrical connection to the surface does not result in shorting out a section of the measuring circuit. In the case of surface temperature measurements on piping, the leads should be wound around the pipe for at least four turns adjacent to the junction.

3.4.1 Thermometer Wells. If the absolute pressure of a confined fluid differs materially from atmospheric pressure, a thermometer cannot be directly immersed in the fluid but should be placed in a suitable thermometer well, as shown in Fig 2. This well is designed to give as high thermal conduction as possible in a radial direction and as low thermal conduction as possible in an axial direction. It must project far enough into the fluid to insure that, in spite of heat emission from its outer end, the bottom of the well attains substantially the temperature of the fluid. An overflow port, shown in Fig 2(A), aids in maintaining the intended depth of immersion of the thermometer.

Table 1
Characteristics of Various Temperature-Measurement Techniques

Technique	Working Temperature Range (°C)	Estimated Uncertainty*	Access Required to Monitor	Type Readout	Adaptable to Recording Instrument	Special Notes
Liquid-in-Glass Thermometer	−200 to 500	0.01 to 2 °C	yes	direct visual sight of column height	no	primarily for fluids and surface temperatures of solids except when well or other provisions are made
Filled-System Thermometer	−240 to 670	0.5 to 1% of span	no	mechanical linkage to pointer	unusual	
Bimetallic Thermometer	−130 to 540	0.5 to 1% of span	no	mechanical linkage to pointer	no	
Thermocouple Thermometer	−180 to 1480	0.1 to 2 °C	no	electrical millivoltmeter	yes	
Resistance Thermometer	−260 to 750	0.001 to 2 °C	no	electrical circuit to meter	yes	
Infrared-Radiation Thermometer Systems [†]	−50 to 150 (to 3000 in special applications)	0.2 to 5 °C	no	meter or visual image display	no	used principally for detection of hot spots in electrical equipment
Change in Resistance Method	−20 to 250	depends upon winding resistance and method used	access to winding terminals required	mathematical conversion of resistance to temperature	no	for obtaining average winding temperatures only; winding normally is deenergized
Temperature-Sensitive Materials	38 to 600 (to 1700 in special applications)	1% for fusible types 10 to 15 °C for pigment types	access to surface being monitored is necessary	sensitive material physical change	no	temperature-sensitive materials change physical appearance when their calibrated temperature is reached; material applied to surface to be monitored

* Estimated uncertainty varies with type of device, scale of readout device, quality, and temperature being determined.

† The characteristics given are those of instruments of importance in temperature measurements of electric apparatus.

Table 2
Temperature-Measurement Techniques for Specific Applications

Application		Technique								
		Liquid-in-Glass Thermometer	Filled-System Thermometer	Bimetallic Thermometer	Thermocouple Thermometer	Resistance Thermometer	Infrared-Radiation Thermometer	Change in Resistance Method	Temperature-sensitive Materials	Embedded Detectors
Development Testing, Production Testing, Problem Investigation	Cooling medium (liquid or gas)	X	X		X	X				
	Transformer windings, motor and generator stator windings				X	X		X		X
	Windings of motor and generator rotors				X			X		
								X		X
	Magnetic materials in transformers, motor, and generator stators				X					X
	Magnetic materials in rotors of rotating machinery						X		X	
	Cable				X			X		
Operating Machinery for Operational Records	Stationary windings of transformers, motors, generators, etc			X	X	X				X
	Cooling medium of transformers and large rotating machines	X	X	X	X	X				
	Static devices (electronic)				X		X			
Maintenance Checks and Failure Investigations		X	X	X	X	X	X	X	X	X

For temperatures up to 200°C, the commonly used filling material for the thermometer well is mercury. A thin layer of oil on top of the mercury reduces the danger from the toxic effects of mercury vapor. Mercury should be used only in well-ventilated areas and cleanup of even small spills should be prompt and thorough. Mercury represents a hazard to equipment as well as to personnel. It amalgamates with copper and silver and their alloys, and extreme care should be taken to insure

that when mercury is used as a well-filling material, none of it is permitted to come in contact with the copper or brass portions of the apparatus or with the operator's rings.

For temperatures that are low and nearly constant, oil may be used as a filling material instead of mercury. Because it readily vaporizes, is subject to excessive convection currents, and has a low thermal conductivity, oil is not suitable if temperatures are high or rapidly varying.

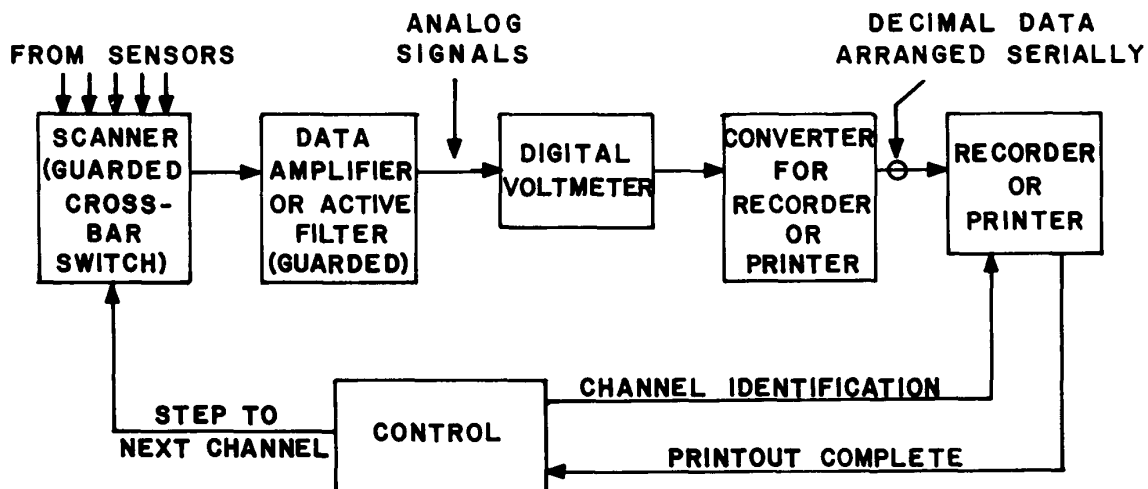


Fig 1
Multiple-Sensor Automatic Data-Logging System

For temperatures between 200°C and 500 °C, solder is a suitable filling material. Thermometers must be removed from cooling solder-filled wells before the solder solidifies. No filling is required in the packed sheath thermocouple (Fig 3).

While in general the use of wells is discouraged, where they must be used, the following precautions are necessary, particularly when the temperature being measured differs by more than 10°C from that of the surroundings.

(1) The material chosen for the wall of the well should be of the highest heat conductivity available consistent with other requirements placed upon it, for example, strength.

(2) The part of the well projecting beyond or outside the vessel must be as small as possible so as to eliminate heat transfer to or from surroundings.

(3) The exposed parts of the well should be covered with a suitable thermal insulating material. The vessel wall should be insulated for some distance from the thermometer well if the vessel is not already insulated, and if such insulation will not materially affect the temperature of the medium to be measured.

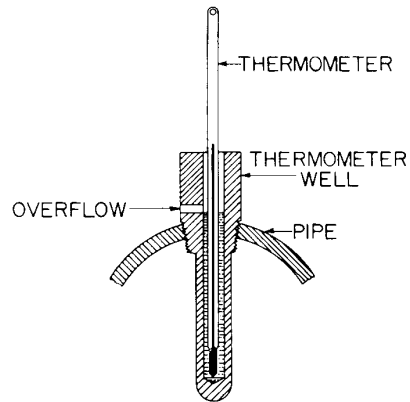
(4) The sensor should be in intimate thermal contact with the well. This may be accomplished by direct contact, as with thermocouples, by heat-transfer filling media or met-

allic sleeves for other thermometers that may be inserted in wells.

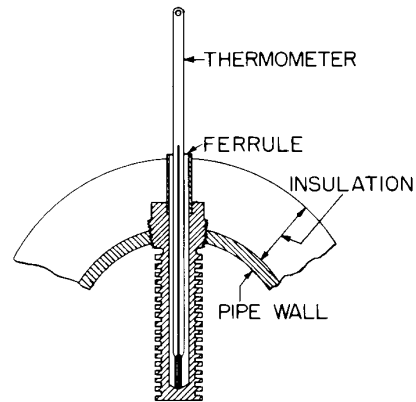
3.4.2 Radiation Shields. When it is necessary to place a temperature-sensing element in a gas at a location where it can receive radiation from, or radiate to, surfaces at temperatures materially different from that of the gas in which it is immersed, shields should be used to intercept the radiation and minimize the resulting errors.

3.5 Embedded Detectors. For temperature measurement by the embedded sensor method, it is important that an especially well-constructed sensor be used because, in most cases, replacement is impossible. Its construction must be such as to withstand the maximum temperatures attained during the manufacture and assembly, as well as during normal service, of the apparatus in which it is used. It must be installed in a manner to avoid interfering in any way with the operation of the apparatus. Each sensor should be protected by an enclosing sheath with leads being brought out to a suitable terminal board mounted on the apparatus.

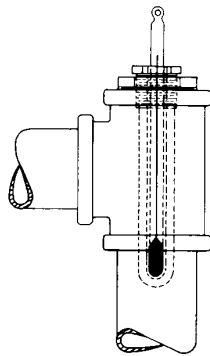
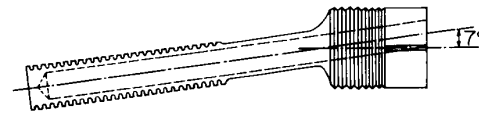
In rotating machines, each sensor should be installed between insulating strips of such dimensions that the assembled unit is as wide as the slot and is somewhat longer than the sensor. The sensor should be located in the



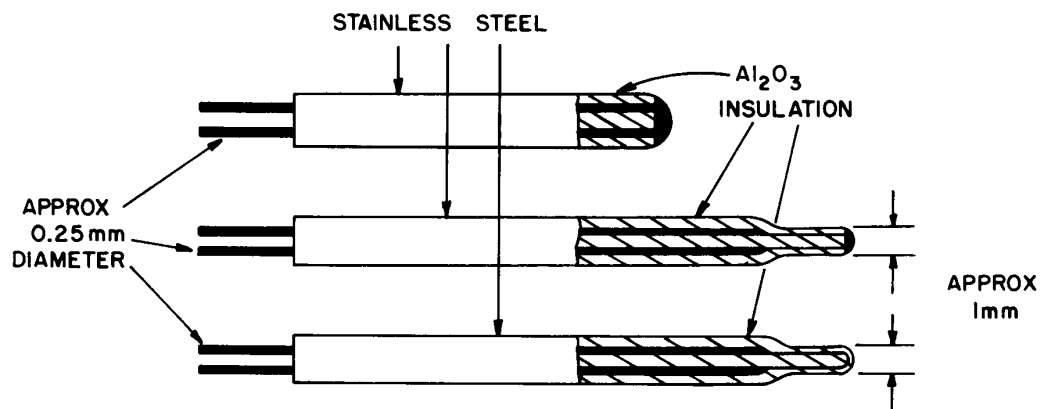
(A) Plain Mercury Well



(B) Improved Finned Mercury Well

(C) Method of Installing Thermometer Wells in
Pipe Lines Smaller Than 10 cm

(D) Finned Well for Vertical Pipes

Fig 2
Thermometer WellsFig 3
Sheathed Thermocouples

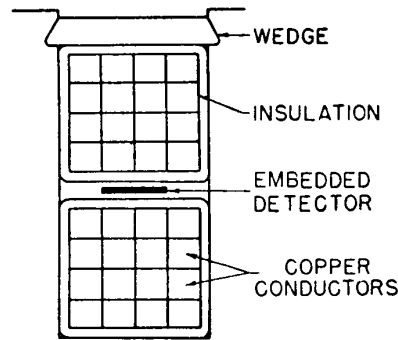


Fig 4
Installation of Embedded Detector

middle of the slot width and, if possible, in intimate contact with the insulation of both the upper and lower coil sides, or in intimate contact with the insulation of the coil side that is nearer the air gap. See Fig 4.

Each sensor should be installed and its leads brought out in such a manner that it is effectually protected from contact with cooling air. If the length of the sensor is less than that of the core, access of air to the sensor should be prevented by suitable packing inserted between the coils and extending to the ends of the core.

The dimensions of the sensor should be such that its temperature represents the average temperature of the zone in which the measurement is desired.

3.6 Sources of Error.² In the case of measurements intended to be made under steady-state conditions, the mere attainment of a constant temperature reading is not in itself adequate. Because of the natural tendency toward temperature equalization, flow of heat from regions of higher temperature to regions of lower temperature will take place. For this reason, in general, introduction of the thermometer will alter the temperature it is desired to measure. The instrumentation should be designed to minimize this effect and appropriate corrections made where they can be evaluated.

It cannot be too strongly emphasized that the influence of dynamic effects must be rec-

ognized and evaluated. In temperature measurement, one of the important dynamic effects is associated with the lag in the measuring equipment in either responding to a change in temperature or indicating such change. Failure of an instrument to indicate a change in temperature may not in itself be positive proof that no change has taken place. The sluggishness of the measuring equipment in responding to change may serve to obscure the actual conditions.

In selecting and using temperature-measuring equipment, this dynamic or lag effect should be taken into consideration. Some of the factors to be considered are the following:

- (1) Heat capacity of the sensor
- (2) Heat capacity of any accessories such as wells or protecting tubes
- (3) Physical proportions and characteristics of the sensor or accessories that will influence the heat-transfer coefficients
- (4) Rate of temperature change in the material being measured
- (5) Mechanical or electrical characteristics of the temperature-measuring equipment

4. Temperature-Measuring Instruments

4.1 Liquid-in-Glass Thermometers.

4.1.1 Principles of Operation. The operation of a liquid-in-glass thermometer depends upon the coefficient of expansion of the liquid being greater than that of the bulb glass. As a consequence, an increase in the temperature of the bulb causes liquid to be expelled from the bulb, resulting in a rise in position of the end of the liquid column. The capillary stem attached to the bulb serves to magnify this change in volume.

4.1.2 Classification.

4.1.2.1 Etched-Stem-Type Thermometer (Laboratory and Chemical Thermometers).

4.1.2.1.1 Partial-Immersion Thermometer. A partial-immersion thermometer [Figs 5 and 6(B)] is one that is designed to indicate temperature correctly when used with the bulb and a specified part of the stem exposed to the temperature being measured. The remaining part of the stem will be at the ambient temperature, usually different from the temperature being measured. Such thermom-

²ASME publication PTC 19.3-1974, Temperature Measurement, Instruments and Apparatus, contains an extended discussion of methods of calibrating thermometers and their associated measuring instruments.

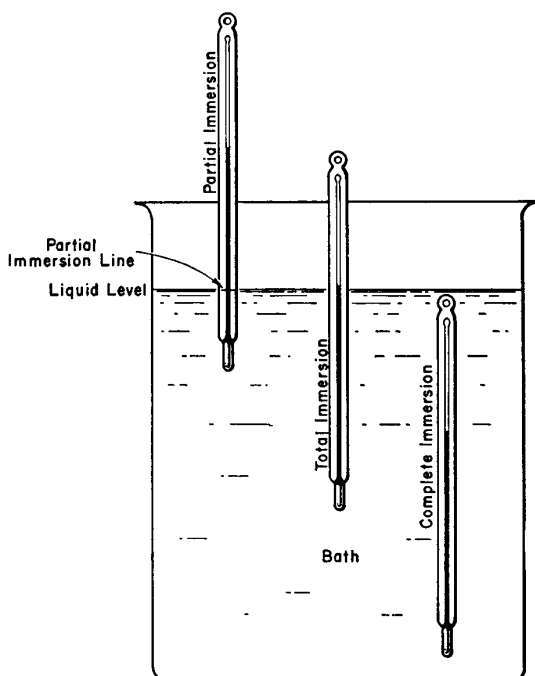


Fig 5
Partial, Total, and Complete Immersion
Thermometers

eters are marked with an immersion line to indicate the proper depth of immersion. The emergent stem refers to the length of liquid column and stem at the ambient temperature.

4.1.2.1.2 Total-Immersion Thermometer. A total-immersion thermometer [Figs 5 and 6(A)] is one that is designed to indicate temperature correctly when used with the bulb and the entire liquid column in the stem exposed to the temperature being measured, but with the gas above the liquid exposed to a temperature that may or may not be different.

4.1.2.1.3 Complete-Immersion Thermometer. A complete-immersion thermometer (Fig 5) is one that is designed to indicate temperatures correctly when the whole thermometer, including the expansion chamber, is exposed to the temperature being measured. In gas-filled thermometers the reading will be different for complete, as compared to total immersion, as a result of the effect of temperature on the gas pressure in the thermometer. The difference in readings under the two con-

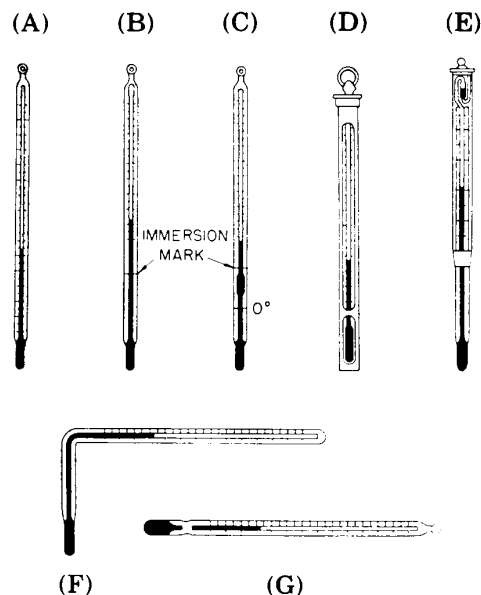


Fig 6
Etched-Stem Liquid-in-Glass Thermometers
(A) Total Immersion (B) Partial Immersion
(C) Partial Range (D) Armored (E) Beckman
Differential (F) Angle Stem (G) Maximum,
Registering

ditions is particularly significant at high temperatures.

4.1.2.1.4 Partial-Range Thermometer. A partial-range thermometer [Fig 6(C)] has an enlargement in the capillary just above the bulb. Without requiring an excessive length of the emergent stem, this construction permits, over a limited temperature range, an expanded scale with large graduations. In partial-immersion thermometers, the enlargement must be well below the immersion line.

4.1.2.1.5 Armored Thermometer. A metal armor [Fig 6(D)], providing protection and mechanical support, is obtainable for etched-stem thermometers. It may be used where the increased time-lag and stem-temperature errors are permissible.

4.1.2.1.6 Beckman Differential Thermometer. The Beckman differential thermometer [Fig 6(E)] is usually made with a short-range interval such as 5°C and a very open scale having, for example, 0.01°C sub-

divisions. The range can be varied at will by changing the amount of mercury in the bulb, any excess being retained in a reservoir at the top.

4.1.2.1.7 Registering-Type Thermometer. The common form of liquid-in-glass thermometer is nonregistering and must be read while immersed in the medium whose temperature is being measured. Thermometers of a registering type are used for the measurement of temperature in locations where the thermometer can be observed only after it has been taken from the medium whose temperature is being measured. These thermometers are generally of the etched-stem type.

4.1.2.1.7.1 Maximum-Registering Type. The maximum-registering type [Fig 6(G)] contains mercury (or mercury-thallium alloy) under vacuum and indicates the maximum temperature to which the bulb has been exposed subsequent to resetting. Built into the bore just above the bulb is a constriction that allows mercury to squeeze through on rising temperatures, but prevents the mercury from returning to the bulb except when extraordinary force is applied, as by shaking toward the bulb.

4.1.2.1.7.2 Minimum-Registering and Maximum-Minimum-Registering Types The minimum-registering and combination maximum-minimum types usually use alcohol or an alcohol-creosote mixture and depend upon surface forces to move an index within the liquid column.

4.1.2.2 Industrial-Type Thermometer. In this type, the bulb and a portion of the stem are enclosed in a metal tube while the scale section is contained in an attached metal case (see Fig 7). The scale is engraved or printed on metal plates fastened to the inside of the case. The case opening is generally closed by a glass window. Industrial thermometers are available in a variety of stem lengths, case sizes, and case-stem angles. The bulb chamber or sensitive portion may be immersed directly in the medium whose temperature is being measured, or it may be inserted in a well (separable socket) [Fig 7(B)], which in turn is immersed. Where the thermometer is mounted in an essentially permanent manner, the extension of the bulb assembly incorporates a threaded swivel nut connection. Union bushing and flange connections are also available

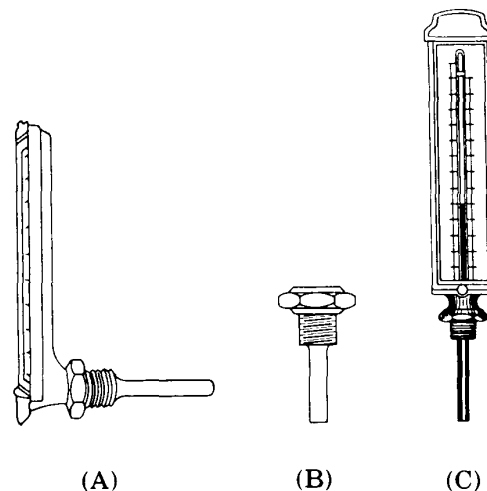


Fig 7
Industrial Liquid-in-Glass Thermometers
(A) Angle Stem (B) Separable Socket
(C) Straight Stem

as alternative means of mounting. Some types are used at various immersions and are termed plain bulb style. No threaded connection is included with this type. Because of their massive metal parts, industrial thermometers are usually less suitable for tests of electrical apparatus than are etched-stem thermometers.

4.1.3 Characteristics.

4.1.3.1 Working Ranges and Choice of Liquid. The working ranges for several liquids used are as follows:

Liquid	Range ($^{\circ}\text{C}$)
Mercury	- 38 to 500
Alcohol	- 70 to 120
Toluol	- 100 to 20
Pentane	- 185 to 20

In general, mercury thermometers are preferable to nonmetallic thermometers. Their accuracy is greater because, in contrast to the other liquids, mercury gives a more sharply defined meniscus and a smaller stem-temperature correction, and it does not wet the capillary. Mercury thermometers should not be used in locations where voltage gradients are too high for the safe introduction of extraneous conductors, or where the mercury released by accidental breakage would cause a

condition hazardous either to persons or to equipment, such as in the oil of a transformer.

4.1.3.2 Sensitivity. Sensitivity is determined by the cross-section area of the capillary bore and the proportion of that area to the volume of the bulb. Application conditions frequently limit the length of scale and the size of bulb. Practical limitations of tubing and thermometer manufacture are significant factors in establishing minimum bore diameters. Sensitivities far in excess of the long-term stability are misleading and generally are costly.

4.1.3.3 Accuracy. Accuracy is dependent not only upon the sensitivity or precision, but also upon the accuracy of calibration or standardization. Because of instability of bulb dimensions, a liquid-in-glass thermometer may undergo a change of calibration with age. This change is most conveniently detected by checking the 0°C point while the thermometer is in good thermal contact with melting ice. Therefore, a thermometer which has the 0°C point engraved on its stem [Fig 6(C)] is to be preferred. With well-designed thermometers, the accuracy of calibration attainable is a function of range and graduation interval. The NBS (National Bureau of Standards) reporting tolerances for such thermometers are listed in Tables 3 and 4.

NOTE: A packed slush made of shaved clear ice and distilled water is best for checking the 0°C point of a liquid-in-glass thermometer. All space between the ice shavings must be filled with water and any excess water on the top must be removed. Care must be taken to prevent contamination of the ice and water.

The values shown in Tables 3 and 4 in the column labeled "Tolerance" represent acceptable limits of error of high-quality thermometers without application of corrections. The values listed in the column headed "Accuracy" represent the limit of error to be anticipated when corrections are applied and when proper attention to such details as maintenance of correct immersion, avoidance of parallax, etc., is exercised in the use of the thermometers. The values shown in the column headed "Corrections Stated to" represent the limits to which NBS considers it appropriate to round off reported values.

With extreme care and attention to detail, the limits of accuracy listed in Tables 3 and 4 might be made smaller, but usually it is pref-

erable to use another type of measuring device, such as a platinum resistance thermometer, if a higher order of accuracy is required. Because of the uncertainty of measurement of the temperature of an emergent column, partial-immersion thermometers generally cannot be expected to give results of the same accuracy as otherwise equivalent design total-immersion thermometers. The etched-stem form is to be relied upon for results of the highest accuracy. The industrial and tube-and-scale forms are affected by heat conduction of the parts other than the glass tube. Such heat transfer is difficult to measure accurately and results in uncertainties in temperature measurement.

4.1.3.4 Response Time. The response time is dependent upon the dimensions and material of the thermometer bulb, the medium in which it is immersed, and the rate at which this medium is stirred. For instance, the response time when in the still air of a room would be perhaps 50 times that of the same thermometer when immersed in a well-stirred water bath.

Since the response time for mercury thermometers is not large, being from 2 to 10 s in a well-stirred water bath, it is not generally necessary to correct for it. For example, if two thermometers, one having a response time of 3 and another of 8 s, are read simultaneously in a bath whose temperature is rising at the rate of 0.001°C in 5 s, the former will read 0.001°C higher than the latter.

Fig 8 shows the approach of thermometer readings to the water bath temperature for 3 selected thermometers. For example, if the thermometer for which the response time is 2.2 s is initially at 25°C and then is immersed in a bath at 75°C, the thermometer reading will be within 0.05°C (0.1 percent of 50°C) of the bath temperature in 15 s and within 0.01°C in 19 s. The curve for 3.1 s response time was obtained for an ASTM (American Society for Testing and Materials) specification 56C calorimeter thermometer with a bulb diameter (outside) of 7.9 mm and a bulb length of 44 mm. The value of 2.2 s was found for an ASTM 7C thermometer having corresponding bulb dimensions of 5.4 and 12 mm. The third curve, for 1.7 s, was obtained for a bulb with corresponding dimensions of 5.4 and 34 mm. It is probable that most solid-stem