TO STUDY AND USED OF THERMOCOUPLE FOR TEMPERATURE MEASURMENT IN EXPERIMENT WORK

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ABSTRACT

Experimental investigations on several commercially available and are conducted in industries to evaluate performance trends. Experimental are analyzed and the parameters determining the performance and working of thermocouple . It is found that how we used thermocouple with different application in industrial sector with different works. Finally, the thermocouple has much more applications and in the paper work also show analysis for easily used in engineering sector.

Keywords: *Introduction, Principle of operation, Types and its Applications.*

I. INTRODUCTION

A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots, where a temperature differential is experienced by the different conductors (or semiconductors). It produces a voltage when the temperature of one of the spots differs from the reference temperature at other parts of the circuit. Thermocouples are a widely used type of temperature sensor for measurement and control and can also convert a temperature gradient into electricity. Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

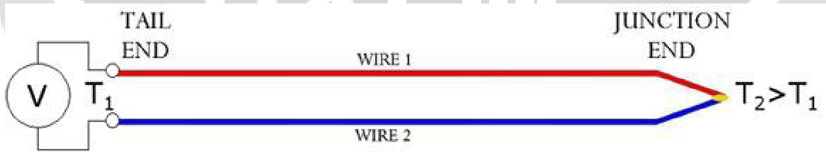


Fig. Schematic drawing of a thermocouple

Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple. Where the measurement point is far from the measuring instrument, the intermediate connection can be made by extension wires which are less costly than the materials used to make the sensor. Thermocouples are usually standardized against a reference temperature of degrees Celsius; practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements.

Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes.

Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered major appliances.

PRINCIPLE OF 0PERATION

In 1821, the German–Estonian physicist Thomas Johann Seebeck discovered that when any conductor is subjected to a thermal gradient, it will generate a voltage. This is now known as thethermoelectric effect or Seebeck effect. Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor experiences the same temperature gradient and also develops a voltage, which normally opposes the original. Fortunately, the magnitude of the effect depends on the metal in use, and so a nonzero voltage will be measured if two dissimilar metals are used. After carefully calibrating the temperature-voltage dependence for a given pair of metals, these metals can be used as a thermometer.

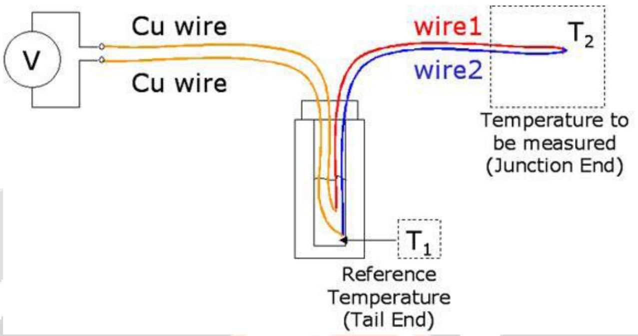
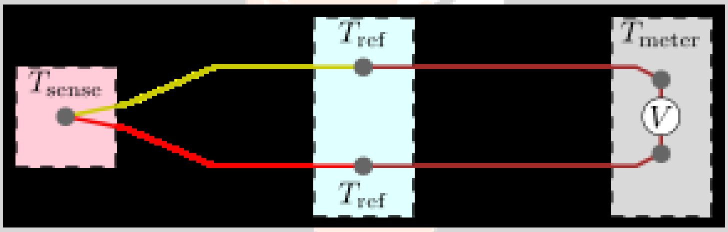


Fig.- A measuring system for thermocouples



K-type thermocouple (chromel–alumel) in the standard thermocouple measurement configuration. The measured voltage can be used to calculate temperature , provided that temperature is known. The standard configuration for thermocouple usage is shown in the figure. Briefly, the desired temperature *T*sense is obtained using three inputs—the characteristic function *E*(*T*) of the thermocouple, the measured voltage *V*, and the reference junctions' temperature *T*ref. The solution to the equation *E*(*T*sense) = *V* + *E*(*T*ref) yields *T*sense. These details are often hidden from the user since the reference junction block (with *T*ref thermometer), voltmeter, and equation solver are combined into a single product.

PHYSICAL PRINCIPLE: SEEDBECK EFFECT

The Seebeck effect creates an electromotive force wherever there is a temperature gradient. This electromotive force can be used to perform work, however in the thermocouple it is used to develop an open-circuit voltage. Under open-circuit conditions where there is no internal current flow, the gradient of voltage (V) is directly proportional to the gradient in temperature (T):
Where **S (T)** is a temperature-dependent material property known as the See beck coefficient.
The measured voltage can be found by adding up (integrating) the electromotive forces along the entire path from the negative terminal of the voltmeter to the positive terminal. The standard measurement configuration, exemplified in the figure, has four temperature gradient regions and thus four voltage contributions:
1. Change from Tmeter to Tref , in the lower copper wire.
2. Change from Tref to Tsense , in the alumel wire.
3. Change from Tsense to Tref , in the chromel wire.
4. Change from Tref to T meter , in the upper copper wire.

Types

Certain combinations of alloys have become popular as industry standards. Selection of the combination is driven by cost, availability, convenience, melting point, chemical properties, stability, and output. Different types are best suited for different applications. They are usually selected on the basis of the temperature range and sensitivity needed. Thermocouples with low sensitivities (B, R, and S types) have correspondingly lower resolutions. Other selection criteria include the chemical inertness of the thermocouple material, and whether it is magnetic or not. Standard thermocouple types are listed below with the positive electrode (assuming) first, followed by the negative electrode.

Thermocouple type	Positive Thermoelement	Negative Thermoelement
B	Pt-30%Rh	Pt-6%Rh
R	Pt-13%Rh	Pt
S	Pt-10%Rh	Pt
K	Ni-10%Cr	Ni-5% other elements
N	Ni-14%Cr-1.5%Si	Ni-4.5%Si-0.1%Mg
E	Ni-10%Cr	45%Ni-55%Cu
J	Fe	45%Ni-55%Cu

REFRACTORY THERMOCOUPLES

Type : R, S, B
Element Dia : 0.30, 0.35, 0.4, 0.45, 0.5 (mm) other
Sizes on request
Protection Sheath : Ceramic (C-799), 610, Inconel, Silicon carbide etc.
Configuration : Simplex/Duplex/Multipoint.
Special : Hot Blast & Stove dome Thermocouples
For Glass Industry-

1) Tri level Thermocouples
2) Fore-hearth Thermocouples
3) Furnace Bottom Thermocouples
4) Distributor Thermocouples
5) Furnace Crown Thermocouples
6) Refiner Thermocouples
7) Annealing Lehr Thermocouples
8) Spout Bowl Thermocouples
9) Glass Level Probes
10) Fish-Hook Thermocouples

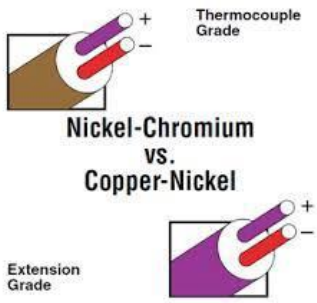
THERMOCOUPLES

High Accurate RTDs for General and Critical applications
Type : Pt 100, 200, 500, 1000 etc.
Element size (MI) : Wire wound ceramic encapsulated
Wire wound glass encapsulated Thin film ceramic encapsulated
Connection : 2, 3, 4, wire
Accuracy : Class A, B, ½, 1/3, 1/5, 1/10, DIN
Protection Sheath : SS304, SS321, SS316, SS310, Inconel
600/800, HRS 446, Hastalloy, Monel etc.
Configuration : Simplex/Duplex/Others

Nickel alloy thermocouples

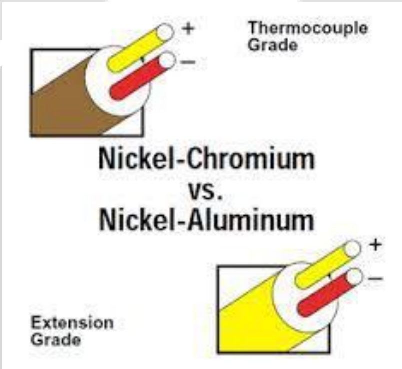
Type E

Type E (chromel – constantan) has a high output (68 µV/°C) which makes it well suited to cryogenic use. Additionally, it is non-magnetic. Wide range is −50 °C to +740 °C and Narrow range is −110 °C to +140 °C.



Type J

Type J (iron – constantan) has a more restricted range (−40 °C to +750 °C) than type K , but higher sensitivity of about 50 µV/°C. The Curie point of the iron (770 °C) causes a smooth change in the characteristic, which determines the upper temperature limit.



Type K

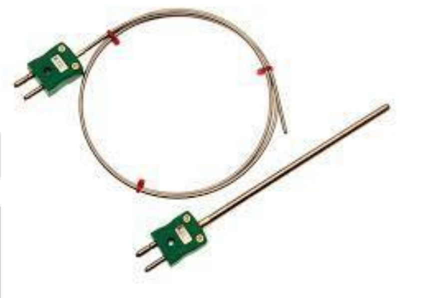
Type K (chromel – alumel) is the most common general purpose thermocouple with a sensitivity of approximately 41 µV/°C (chromel positive relative to alumel when the junction temperature is higher than the reference temperature).[9] It is inexpensive, and a wide variety of probes are available in its −200 °C to +1350 °C / -330 °F to +2460 °F range. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics may vary considerably between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouples made with magnetic material is that they undergo a deviation in output when the material reaches its Curie point; this occurs for type K thermocouples at around 185 °C. Type K thermocouples may be used up to 1260 °C in non-oxidizing or inert atmospheres without rapid aging. In marginally oxidizing atmospheres (such as carbon dioxide) between 800 °C–1050 °C, the chromel wire rapidly corrodes and becomes magnetic in a phenomenon known as "green rot"; this induces a large and permanent degradation of the thermocouple, causing the thermocouple to read too low if the corroded area is exposed to thermal gradient. Another source of drift in type K thermocouples is that near 400 °C, a slow reordering in the chromel wire occurs; this is reversible and leads to hysteresis between heating and cooling.

Type M

Type M (Ni/Mo 82%/18% – Ni/Co 99.2%/0.8%, by weight) are used in vacuum furnaces for the same reasons as with type C (described below). Upper temperature is limited to 1400 °C. It is less commonly used than other types.

Type N

Type N (Nicrosil – Nisil) thermocouples are suitable for use between −270 °C and +1300 °C owing to its stability and oxidation resistance. Sensitivity is about 39 µV/°C at 900 °C, slightly lower compared to type K.



Designed at the Defence Science and Technology Organisation (DSTO) of Australia, by Noel A. Burley, type N thermocouples overcome the three principal characteristic types and causes of thermoelectric instability in the standard base-metal thermoelement materials:

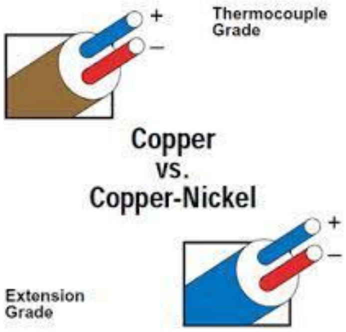
1. A gradual and generally cumulative drift in thermal EMF on long exposure at elevated temperatures. This is observed in all base-metal thermoelement materials and is mainly due to compositional changes caused by oxidation, carburization, or neutron irradiation that can produce transmutation in nuclear reactor environments. In the case of type K thermocouples, manganese and aluminium atoms from the KN (negative) wire migrate to the KP (positive) wire, resulting in a down-scale drift due to chemical contamination. This effect is cumulative and irreversible.
2. A short-term cyclic change in thermal EMF on heating in the temperature range ca. 250– 650 °C, which occurs in types K, J, T, and E thermocouples. This kind of EMF instability is associated with structural changes such as magnetic short range order in the metallurgical composition.

3. A time-independent perturbation in thermal EMF in specific temperature ranges. This is due to composition-dependent magnetic transformations that perturb the thermal EMFs in type K thermocouplees in the range ca. 25-225°C, and in type J above 730 °C.

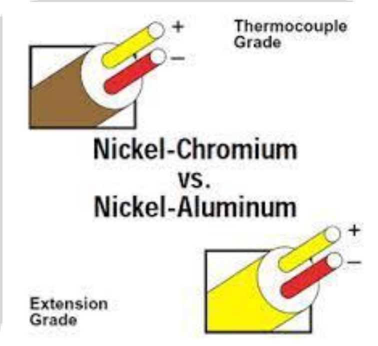
The Nicrosil and Nisil thermocouple alloys show greatly enhanced thermoelectric stability relative to the other standard base-metal thermocouple alloys because their compositions substantially reduce the thermoelectric instabilities described above. This is achieved primarily by increasing component solute concentrations (chromium and silicon) in a base of nickel above those required to cause a transition from internal to external modes of oxidation, and by selecting solutes (silicon and magnesium) that preferentially oxidize to form a diffusion-barrier, and hence oxidation-inhibiting films.

Type T

Type T (copper – constantan) thermocouples are suited for measurements in the −200 to 350 °C range. Often used as a differential measurement since only copper wire touches the probes. Since both conductors are non-magnetic, there is no Curie point and thus no abrupt change in characteristics. Type T thermocouples have a sensitivity of about 43 µV/°C. Note that copper has a much higher thermal conductivity than the alloys generally used in thermocouple constructions, and so it is necessary to exercise extra care with thermally anchoring type T thermocouples.



Type B
Type B thermocouples (Pt/Rh 70%/30% – Pt/Rh 94%/6%, by weight) are suited for use at up to 1800 °C. Type B thermocouples produce the same output at 0 °C and 42 °C, limiting their use below about 50 °C. The emf function has a minimum around 21 °C, meaning that cold junction compensation is easily performed since the compensation voltage is essentially a constant for a reference at typical room temperatures.



Type S
Type S thermocouples (Pt/Rh 90%/10% – Pt, by weight), similar to type R, are used up to 1600 °C. Before the introduction of the International Temperature Scale of 1990 (ITS-90), precision type S thermocouples were used as the practical standard thermometers for the range of 630 °C to 1064 °C, based on an interpolation between the freezing points of antimony, silver, and gold. Starting with ITS- 90, platinum resistance thermometershave taken over this range as standard thermometers.

Tungsten/rhenium alloy thermocouples
These thermocouples are well-suited for measuring extremely high temperatures. Typical uses are hydrogen and inert atmospheres as well as vacuum furnaces. They are not used in oxidizing environments at high temperatures because of embrittlement. A typical range is 0 to 2315 °C, which can be extended to 2760 °C in inert atmosphere and to 3000 °C for brief measurements.

Thermocouple characteristics at low temperatures. The AuFe-based thermocouple shows a steady sensitivity down to low temperatures, whereas conventional types soon flatten out and lose sensitivity at low temperature. In these thermocouples (chromel – gold/iron alloy), the negative wire is gold with a small fraction (0.03–0.15 atom percent) of iron. The impure gold wire gives the thermocouple a high sensitivity a low temperatures (compared to other thermocouples at that temperature), whereas the chromel wire maintains the sensitivity near room temperature. It can be used for cryogenic applications (1.2–300 K and even up to 600 K). Both the sensitivity and the temperature range depend on the iron concentration. The sensitivity is typically around 15 μV/K at low temperatures, and the lowest usable temperature varies between 1.2 and 4.2 K.

Type P (noble metal alloy)
Type P or Platinel II (Pd/Pt/Au 55%/31%/14% – Au/Pd 65%/35%, by weight) thermocouples give a thermoelectric voltage that mimics the type K over the range 500 °C to 1400 °C, however they are constructed purely of noble metals and so shows enhanced corrosion resistance. This combination is known as Platinel II.

Platinum/molybdenum alloy thermocouples
Thermocouples of platinum/molybdenum alloy (Pt/Mo 95%/5% – Pt/Mo 99.9%/0.1%, by weight) are sometimes used in nuclear reactors as they show a low drift from nuclear transmutation as induced by neutron irradiation, compared to the platinum/rhodium alloy types.

Iridium/rhodium alloy thermocouples

The use of two wires of iridium/rhodium alloys can provide a thermocouple that can be used up to about 2000 °C in inert atmospheres.

Pure noble metal thermocouples Au–Pt, Pt–Pd

Thermocouples made up of two different, high-purity noble metals can show high accuracy even when uncalibrated, as well as low levels of drift. Two combinations in use are gold–platinum and platinum–Palladium. Their main limitations are the low melting points of the metals involved (1064 °C for gold and 1555 °C for palladium). These thermocouples tend to be more accurate than type S, and due to their economy and simplicity are even regarded as competitive alternatives to the platinum resistance thermometers that are normally used as standard thermometers.

THERMOCOUPLE INSULATION

The wires that make up the thermocouple must be insulated from each other everywhere, except at the sensing junction. Any additional electrical contact between the wires, or contact of a wire to other conductive objects, can modify the voltage and give a false reading of temperature. Plastics are suitable insulators for low temperatures parts of a thermocouple, whereas ceramic insulation can be used up to around 1000 °C. Other concerns (abrasion and chemical resistance) also affect the suitability of materials. When wire insulation disintegrates, it can result in an unintended contact away from the desired sensing point. If such a damaged thermocouple used in the closed loop control of a thermostat or other temperature controller, this can lead to a runaway overheating event and possibly severe damage, as the false temperature reading will typically be lower than the sensing junction temperature. Failed insulation will also typically outgas, which can lead to process contamination. For parts of thermocouples used at very high temperatures or in contamination-sensitive applications, the only suitable insulation may be vacuum or inert gas; the rigidity of the thermocouple wires is used to keep them separated.

APPLICATION

Thermocouples are suitable for measuring over a large temperature range, from −270 up to 3000 °C (for a short time, in inert atmosphere). Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, other industrial processes and fog machines. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0–100 °C with 0.1 °C accuracy. For such applications thermistors, silicon band gap temperature sensors and resistance thermometers are more suitable.

Steel industry

Type B, S, R and K thermocouples are used extensively in the steel and iron industries to monitor temperatures and chemistry throughout the steel making process. Disposable, immersible, type S thermocouples are regularly used in the electric arc furnace process to accurately measure the temperature of steel before tapping. The cooling curve of a small steel sample can be analyzed and used to estimate the carbon content of molten steel.

Gas appliance safety

A thermocouple (the right most tube) inside the burner assembly of a water heater.

Thermocouple connection in gas appliances. The end ball (contact) on the left is insulated from the fitting by an insulating washer. The thermocouple line consists of copper wire, insulator and outer metal (usually copper) sheath which is also used as ground. Many gas-fed heating appliances such as ovens and water heaters make use of a pilot flame to ignite the main gas burner when required. If the pilot flame goes out, unburned gas may be released, which is an explosion risk and a health hazard. To prevent this, some appliances use a thermocouple in a failsafe circuit to sense when the pilot light is burning. The tip of the thermocouple is placed in the pilot flame, generating a voltage which operates the supply valve which feeds gas to the pilot. So long as the pilot flame remains lit, the thermocouple remains hot, and the pilot gas valve is held open. If the pilot light goes out, the thermocouple temperature falls, causing the voltage across the thermocouple to drop and the valve to close. Some combined main burner and pilot gas valves (mainly by Honeywell) reduce the power demand to within the range of a single universal thermocouple heated by a pilot (25 mV open circuit falling by half with the coil connected to a 10–12 mV, 0.2–0.25 A source, typically) by sizing the coil to be able to hold the valve open against a light spring, but only after the initial turning-on force is provided by the user pressing and holding a knob to compress the spring during lighting of the pilot.

These systems are identifiable by the 'press and hold for x minutes' in the pilot lighting instructions. (The holding current requirement of such a valve is much less than a bigger solenoid designed for pulling the valve in from a closed position would require.) Special test sets are made to confirm the valve let-go and holding currents, because an ordinary milliammeter cannot be used as it introduces more resistance than the gas valve coil. Apart from testing the open circuit voltage of the thermocouple, and the near shortcircuit DC continuity through the thermocouple gas valve coil, the easiest non-specialist test is substitution of a known good gas valve. Some systems, known as millivolt control systems, extend the thermocouple concept to both open and close the main gas valve as well. Not only does the voltage created by the pilot thermocouple activate the pilot gas valve, it is also routed through a thermostat to power the main gas valve as well. Here, a larger voltage is needed than in a pilot flame safety system described above, and a thermopile is used rather than a single thermocouple. Such a system requires no external source of electricity for its operation and thus can operate during a power failure, provided that all the other related system components allow for this. This excludes common forced air furnaces because external electrical power is required to operate the blower motor, but this feature is especially useful for un-powered convection heaters.

A similar gas shut-off safety mechanism using a thermocouple is sometimes employed to ensure that the main burner ignites within a certain time period, shutting off the main burner gas supply valve should that not happen. Out of concern about energy wasted by the standing pilot flame, designers of many newer appliances have switched to an electronically controlled pilot-less ignition, also called intermittent ignition. With no standing pilot flame, there is no risk of gas buildup should the flame go out, so these appliances do not need thermocouple-based pilot safety switches. As these designs lose the benefit of operation without a continuous source of electricity, standing pilots are still used in some appliances. The exception is later model instantaneous (aka "tankless") water heaters that use the flow of water to generate the current required to ignite the gas burner; these designs also use a thermocouple as a safety cut-off device in the event the gas fails to ignite, or if the flame is extinguished.

Thermopile radiation sensors

Thermopiles are used for measuring the intensity of incident radiation, typically visible or infrared light, which heats the hot junctions, while the cold junctions are on a heat sink. It is possible to measure radiative intensities of only a few μW/cm2 with commercially available thermopile sensors. For example, some laser power meters are based on such sensors. The principle of operation of a thermopile sensor is distinct from that of a bolometer, as the latter relies on a change in resistance.

Manufacturing

Thermocouples can generally be used in the testing of prototype electrical and mechanical apparatus. For example, switchgear under test for its current carrying capacity may have thermocouples installed and monitored during a heat run test, to confirm that the temperature rise at rated current does not exceed designed limits.

Power production

Thermoelectric generator
A thermocouple can produce current to drive some processes directly, without the need for extra circuitry and power sources. For example, the power from a thermocouple can activate a valve when a temperature difference arises. The electrical energy generated by a thermocouple is converted from the heat which must be supplied to the hot side to maintain the electric potential. A continuous transfer of heat is necessary because the current flowing through the thermocouple tends to cause the hot side to cool down and the cold side to heat up (the Peltier effect). Thermocouples can be connected in series to form a thermopile, where all the hot junctions are exposed to a higher temperature and all the cold junctions to a lower temperature. The output is the sum of the voltages across the individual junctions, giving larger voltage and power output. In a radioisotope thermoelectric generator, the radioactive decay of transuranic elements as a heat source has been used to power spacecraft on missions too far from the Sun to use solar power. Thermopiles heated by kerosene lamps were used to run batteryless radio receivers in isolated areas. There are commercially produced lanterns that use the heat from a candle to run several light emitting diodes, and thermoelectrically-powered fans to improve air circulation and heat distribution in wood stoves.

Thermoelectric cooling

Thermoelectric cooling
The Peltier effect can be used for cooling, in the reverse process to a thermoelectric generator. Instead of generating electric power, the thermocouple consumes it, working as a heat pump.

Process plants

Chemical production and petroleum refineries will usually employ computers for logging and for limit testing the many temperatures associated with a process, typically numbering in the hundreds. For such cases, a number of thermocouple leads will be brought to a common reference block (a large block of copper) containing the second thermocouple of each circuit. The temperature of the block is in turn measured by a thermistor. Simple computations are used to determine the temperature at each measured location.

Thermocouple as vacuum gauge

A thermocouple can be used as a vacuum gauge over the range of approximately 0.001 to 1 torr absolute pressure. In this pressure range, the mean free path of the gas is comparable to the dimensions of the vacuum chamber, and the flow regime is neither purely viscous nor purely molecular. In this configuration, the thermocouple junction is attached to the centre of a short heating wire, which is usually energised by a constant current of about 5mA, and it is this heat which is removed at a rate related to the thermal conductivity of the gas. It may be possible to superimpose ac heating on the thermocouple directly, making the sensor a 2-wire device, but those on the market appear to all be 4-wire devices, with separate terminals for the heater and the thermocouple. The temperature detected at the thermocouple junction depends on the thermal conductivity of the surrounding gas, which depends on the pressure of the gas. The potential difference measured by a thermocouple is proportional to the square of pressure over the low- to medium-vacuum range. At higher (viscous flow) and lower (molecular flow) pressures, the thermal conductivity of air or any other gas is essentially independent of pressure. The thermocouple was first used as a vacuum gauge by Voege in 1906. The mathematical model for the thermocouple as a vacuum gauge, as explained in detail by Van Atta, is quite complicated but can be simplified to

$$\mathbf{P = B\,(V^2 - V_O) / V^2_O}$$

Where *P* is vacuum pressure; *B* is a constant that depends on the thermocouple temperature, the gas composition and the vacuum chamber geometry; *V0* is the thermocouple voltage as the pressure approaches absolute zero; and *V* is the voltage indicated by the thermocouple. The alternative is the Pirani gauge which operates in a similar way, over approximately the same pressure range, but is only a 2 terminal device, sensing the change in resistance with temperature of a thin electrically heated wire, rather than using a thermocouple.

CONCLUSION

A portable direct-reading diode thermometer has been constructed having an overall accuracy of kO.1"C for the temperature range - 65 to + 50°C, as required for operation in a thermal gradient chamber. Two probe types were evaluated, one with a glass envelope for use in the chamber and one with a stainless-steel envelope which was calibrated as a standard for the system. It is possible, by measurement of the forward voltage across a diode sensor, to determine the probe temperature to better than i0.05’C. Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation.

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