Thermocouple

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In electronics, **thermocouples** are a widely used type of temperature sensor and can also be used as a means to convert thermal potential difference into electric potential difference. They are cheap, interchangeable, have standard connectors, and can measure a wide range of temperatures. The main limitation is accuracy; system errors of less than 1 °C can be difficult to achieve.

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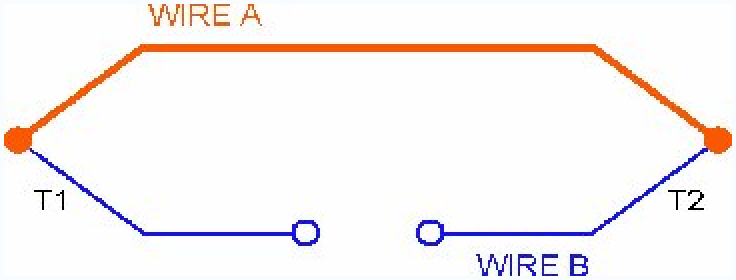
[edit] Principle of operation

In 1821, the German-Estonian physicist Thomas Johann Seebeck discovered that when any conductor (such as a metal) is subjected to a thermal gradient, it will generate a voltage. This is now known as the thermoelectric effect. Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original. Fortunately, the magnitude of the effect depends on the metal in use. Using a dissimilar metal to complete the circuit will have a different voltage generated, leaving a small difference voltage available for us to measure, which increases with temperature. This difference can typically be between 1 to about 70 microvolts per degree Celsius for the modern range of available metal combinations. Certain combinations have become popular as industry standards, driven by cost, availability, convenience, melting point, chemical properties, stability, and output.

It is important to note that thermocouples measure the temperature difference between two points, not absolute temperature.



In most applications, one of the junctions — the *cold junction*— is maintained at a known (reference) temperature, while the other end is attached to a probe. For example, in the image above, the cold junction will be at copper traces on the circuit board. Another temperature sensor will measure the temperature at this point, so that the temperature at the probe tip can be calculated.

Thermocouples can be connected in series with each other to form a **thermopile**, where all the hot junctions are exposed to the higher temperature and all the cold junctions to a lower temperature. Thus, the voltages of the individual thermocouple add up, which allows for a larger voltage.

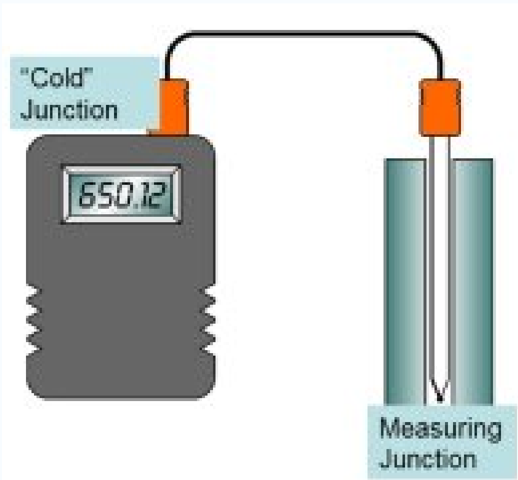
Having available a known temperature cold junction, while useful for laboratory calibrations, is simply not convenient for most directly connected indicating and control instruments. They incorporate into their circuits an artificial cold junction using some other thermally sensitive device (such as a thermister or diode) to measure the temperature of the input connections at the instrument, with special care being taken to minimize any temperature gradient between terminals. Hence, the voltage from a known cold junction can be simulated, and the appropriate correction applied. This is known as *cold junction compensation*.

Usually the thermocouple is attached to the indicating device by a special wire known as the *compensating* or *extension* cable. The terms are specific. *Extension cable* uses wires of nominally the same conductors as used at the thermocouple itself. These cables are less costly than thermocouple wire, although not cheap, and are usually produced in a convenient form for carrying over long distances - typically as flexible insulated wiring or multicore cables. They are usually specified for accuracy over a more restricted temperature range than the thermocouple wires. They are recommended for best accuracy.

Compensating cables on the other hand, are less precise, but cheaper. They use quite different, relatively low cost alloy conductor materials whose net thermoelectric coefficients are similar to those of the thermocouple in question (over a limited range of temperatures), but which do not match them quite as faithfully as extension cables. The combination develops similar outputs to those of the themocouple, but the operating temperature range of the compensating cable is restricted to keep the mis-match errors acceptably small.

The extension cable or compensating cable must be selected to match the thermocouple. It generates a voltage proportional to the difference between the hot junction and cold junction, and is connected in the correct polarity so that the additional voltage is added to the thermocouple voltage, compensating for the temperature difference between the hot and cold junctions.

Ref: "Guide to Thermocouple and Resistance Themometry" pp20 Iss 6.0 TC Ltd.



[edit] Voltage-Temperature Relationship

The relationship between the temperature difference and the output voltage of a thermocouple is nonlinear and is given by a polynomial interpolation.

$$T = \sum_{n=0}^{N} a_n v^n$$

The coefficients a_n are given for n between 5 and 9.

To achieve accurate measurements the equation is usually implemented in a digital controller or stored in a lookup table. Some older devices use analog filters.

[edit] Different types

A variety of thermocouples are available, suitable for different measuring applications (industrial, scientific, food temperature, medical research, etc.).

Type K (Chromel (Ni-Cr alloy) / Alumel (Ni-Al alloy))

The "general purpose" thermocouple. It is low cost and, owing to its popularity, it is available in a wide variety of probes. They are available in the −200 °C to +1200 °C range. The type K was specified at a time when metallurgy was nowhere near as advanced as today and consequently characteristics vary considerably between examples. There is another problem in that one of the consituent metals is magnetic (Nickel). The characteristic of the thermocouple undergoes a step change when a magnetic material reaches its Curie point. This occurs for this thermocouple at 354°C. Sensitivity is approximately 41 µV/°C.

Type E (Chromel / Constantan (Cu-Ni alloy))

Type E has a high output (68 µV/°C) which makes it well suited to low temperature (cryogenic) use. Another property is that it is non-magnetic.

Type J (Iron / Constantan)

Limited range (−40 to +750 °C) makes type J less popular than type K. The main application is with old equipment that cannot accept modern thermocouples. J types cannot be used above 760 °C as an abrupt magnetic transformation causes permanent decalibration. Type J's have a sensitivity of ~52 µV/°C

Type N (Nicrosil (Ni-Cr-Si alloy) / Nisil (Ni-Si alloy))

High stability and resistance to high temperature oxidation makes type N suitable for high temperature measurements without the cost of platinum (B, R, S) types. They can withstand temperatures above 1200 °C. Sensitivity is about 39 µV/°C at 900°C, slightly lower than a Type K. Designed to be an improved type K, it is becoming more popular.

Thermocouple types B, R, and S are all noble metal thermocouples and exhibit similar characteristics. They are the most stable of all thermocouples, but due to their low sensitivity (approximately 10 µV/°C) they are usually only used for high temperature measurement (>300 °C).

Type B (Platinum-Rhodium/Pt-Rh)

Suited for high temperature measurements up to 1800 °C. Unusually type B thermocouples (due to the shape of their temperature-voltage curve) give the same output at 0 °C and 42 °C. This makes them useless below 50 °C.

Type R (Platinum /Platinum with 7% Rhodium)

Suited for high temperature measurements up to 1600 °C. Low sensitivity (10 µV/°C) and high cost makes them unsuitable for general purpose use.

Type S (Platinum /Platinum with 10% Rhodium)

Suited for high temperature measurements up to 1600 °C. Low sensitivity (10 µV/°C) and high cost makes them unsuitable for general purpose use. Due to its high stability type S is used as the standard of calibration for the melting point of gold (1064.43 °C).

Type T (Copper / Constantan)

Suited for measurements in the −200 to 350 °C range. The positive conductor is made of copper, and the negative conductor is made of constantan. Often used as a differential measurement since only copper wire touches the probes. As both conductors are non-magnetic Type T thermocouples are a popular choice for applications such as Electrical Generators which contain strong magnetic fields. Type T thermocouples have a sensitivity of ~43 µV/°C

Thermocouples are usually selected to ensure that the measuring equipment does not limit the range of temperatures that can be measured. Note that thermocouples with low sensitivity (B, R, and S) have a correspondingly lower resolution.

[edit] Applications

Thermocouples are most suitable for measuring over a large temperature range, up to 1800 K. 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 and RTDs are more suitable.

[edit] Steel Industry

Type B,S,R and K thermocouples are used extensively in the steel and iron industry 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 steel temperature before tapping. The cooling curve of a small steel sample can be analyzed and used to estimate the carbon content of molten steel.

[edit] Heating appliance safety

Many gas-fed heating appliances like ovens and water heaters make use of a pilot light to ignite the main gas burner as required. If the pilot light becomes extinguished for any reason, there is the potential for uncombusted gas to be released into the surrounding area, thereby creating both risk of fire and a health hazard. To prevent such a danger, some appliances use a thermocouple to sense when the pilot light is burning. Specifically, the tip of a themocouple is placed in the pilot flame. The thermocouple voltage, typically around 20 mV, operates the gas supply valve responsible for feeding the pilot. So long as the pilot flame remains lit, the thermocouple remains hot and holds the pilot gas valve open. If the pilot light goes out, the temperature will fall along with a corresponding drop in electricity, removing power from the valve. Unpowered, the valve will then automatically shut off the gas, halting this unsafe condition.

Many systems (*Millivolt control* systems) extend this concept to the main gas valve as well. Not only does the electricity 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, for which reason a thermopile is used rather than a single thermocouple. Such a system requires no external source of electricity for its operation and so can operate during a power failure, provided all the related system components allow for this. Note that this excludes common forced air furnaces because external power is required to operate the blower motor, but this feature is especially useful for unpowered 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 for wasted energy, many newer appliances have switched to an electronically controlled pilot-less ignition, also called intermittent ignition. This eliminates the need for a standing pilot flame but loses the benefit of any operation without a continuous source of electricity.

[edit] 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 $\mu W/cm^2$ with commercially available thermopile sensors. For example, laser power meters are based on such sensors.

[edit] Radioisotope thermoelectric generators (RTGs)

Thermopiles can also be applied to generate electricity in radioisotope thermoelectric generators