Why thermocouples measure relative temperatures!

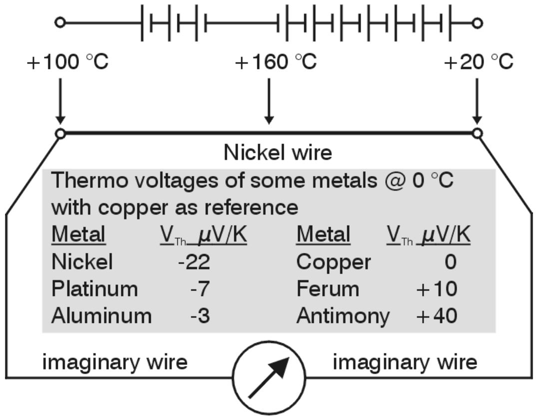
or What is a cold junction?

Why is the thermocouple so popular?

In the measuring and controlling technique the thermocouples are probably the most used temperature sensors. Their simple design, accuracy, short reaction time and good price-performance ratio allow their use in an innumerable number of applications in the measuring technique. By taking into account their characteristic properties and selecting the measuring system accordingly, one can obtain very good measuring results with a simple assembly.

How does a thermocouple work?

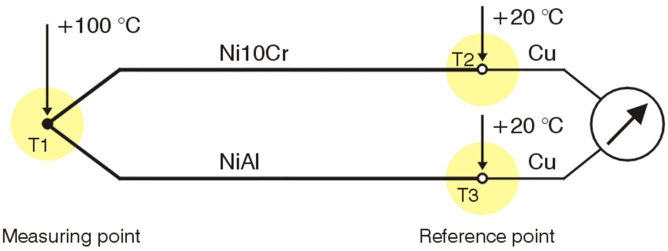
If the temperature along a metal conductor is inhomogeneous, so-called thermo voltages will occur between the points of different temperatures. These are caused by the different bond energies of the electrons to the atoms in the metal grid (high temperature means low bond energy). Imagine this behaviour as a series connection of separate voltage sources. However, it is not possible to measure these voltages in practice, as, even with a high input resistance equipment, current flow and therefore a return conductor is required. This return conductor would be a thermo wire itself. You will not measure any voltage if you connect two wires of the same material for a thermocouple, because the wire ends would have the same electrical charge, the voltage difference would be 0 V.



Equivalent circuit diagram regarding the thermo voltage in the nickel conductor

In order to measure a voltage, the thermocouple must consist of two different metal wires. For example: the thermocouple of type K consists of a positive conductor of nickel-chromium alloy (Ni10Cr), and a negative conductor of nickel-aluminium alloy (NiAl). Therefore, this design results in 3 transition points which will influence the measuring result.

The temperature at the reference point is important



Thermocouple measuring circuit with type K sensors

The above drawing shows 3 independent thermo transitions:

1. Transition T1 from Ni10Cr to NiAl, the original measuring point.
2. Transition T2 from Ni10Cr to Cu and transition T3 from NiAl to Cu, the copper connection lines to the measuring unit. This provides the reference point.

The terminal voltage measured, always corresponds to the differential voltage between the thermo voltage of the measuring point and the reference point! Consequently the ambient temperature at the reference point has a considerable influence on the measured result!

Cold junction compensation at the reference point

The above insights result in the following conclusion:

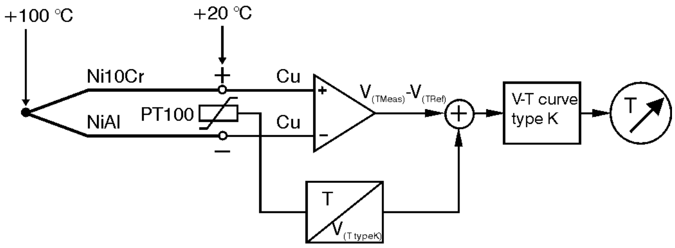
The temperature at the reference point must be kept constant and / or this temperature has to be taken into account for the measured thermo voltage.
With older laboratory systems, the reference point was located in an ice water bath with a constant temperature of 0 °C. Therefore, the measured thermo voltage did always correspond to the absolute temperature of the Celsius scale. This method to correct the measuring point thermo voltage by the thermo voltage of the reference point led to the still often used expression of cold junction compensation.

How is the compensation accomplished?

Today, progress in electronics and computer technology offers much convenient methods of compensation. But the compensation is always realized by an adequate calculation of the respective thermo voltages. The thermo voltage can be computed with the following equation:

$V_{(\Delta T)} = V_{(+100\ °C\ type\ K)} - V_{(+20\ °C\ type\ K)}$

In order to obtain the absolute measuring temperature, it is necessary to measure the terminal temperature at the reference point. For this, a PT100 resistor is usually used at the terminal point. The temperature that the PT100 has determined must then be converted into a corresponding NiCrNi thermo voltage and added to the measured voltage. The resulting value can then be used to obtain the correct temperature either by calculation or a table look-up.



Compensated thermocouple measuring circuit

If the terminal point temperature is erroneously added to the relative temperature obtained from the measured voltage, a considerable error results due to the non-linearity of the thermocouple.

Practical possibilities of compensation

1. Compensation for each measuring channel

The best solution is to compensate channel by channel, i.e. each measuring input gets its own precision sensor at the plug connection resp. the terminal point, which will read the local temperature. Calculation is as shown above. Even gradients in temperature within the socket grouping (e.g. by unilateral heating through sunlight or partial heat loss) are well compensated if the reference sensor is located in the immediate vicinity of the thermo transition. The manufacturing and material costs, however, are comparatively high.

2. Simple compensation in the isothermal block

In order to reduce material cost and / or space, it makes sense to determine the reference temperature via a precision sensor only at one single point resp. at a few points. This requires that all thermo transitions of the connections are assembled in an isothermal block. By using a material with very good heat conduction (e.g. aluminium), a quasi homogenous temperature distribution in the isothermal block can be obtained. This guarantees sufficient accuracy when the reference temperature is measured at a suitable point of the isothermal block. It would also be possible to place one or several precision sensors directly in the housing of the collector plug for the measuring sensor cables.

An appropriate enclosure of the connector (massive, good heat conduction) would enable a good heat distribution and consequently a good compensation. The disadvantage of this variant is that the precision sensor cannot be calibrated during the production of the unit, since the measurement wiring harness normally stays in the vehicle and therefore always changes. This, however, leads to an uncontrollable source of errors due to the tolerances of the precision sensors. Additionally the connection of the reference sensor in the plug would mean a higher expenditure in wiring and additional pins as well.

3. Simple compensation without isothermal block

Compensation with one reference element in the measuring unit and without special procedures to control the temperature distribution is not recommended. This is only suitable for stationary application with constant ambient temperature conditions. Here, the accuracies of the respective measuring channels strongly depend on the mechanical construction and the external thermal influences, since only one channel at most is optimally compensated.

IPETRONIK thermo modules

All thermocouple measuring modules of the IPETRONIK SIM family contain their own PT100 precision sensor in each thermo input socket in order to determine the reference temperature directly at the thermo transition. This guarantees an optimal compensation even under unfavourable ambient conditions.

left: M-THERMO 8 right: SIM-THERMO II-16

IPETRONIK complements its proven thermocouple measuring modules of the SIM family by a compact 8-channel-module of the M-Series. Their small dimensions, high ambient temperature range of up to 120°C, and protection class IP65 allow their use even directly in the motor compartment of the vehicle.