Basic Information on Temperature Sensors

Industrial Automation

The seventh part of our series on the “Basic Principles of Sensor Technology”, produced in collaboration with Hans Turck GmbH & Co.KG, deals with temperature sensors. This article provides a better understanding of some important basic concepts that users will frequently encounter in practice, as well as an explanation of different temperature measuring principles. With the right sensors, companies can implement the automation in their production sites much easier and faster, whilst improving efficiency, quality and safety at the same time.

Together with pressure, temperature is one of the most important measuring variables in the process. The temperature in cooling circuits is not only monitored to ensure quality but also to monitor safety, and in the process industry, processes are controlled by the supply of thermal energy. The right sensor must be selected according to the application at hand. To ensure the optimum measuring result, it is therefore important to be familiar with the application and the disturbance variables involved, as well as to implement appropriate measures

What is hot - what is cold?

We are able to detect temperature differences and classify them thanks to the sensory apparatus of our own body. However, whilst we can define a body as cold or warm we are not able to quantify temperature itself. What, anyway, does temperature mean? Temperature describes the average kinetic energy per particle in a sample of matter. How can this type of energy be described in a scale in order to quantify temperature?

To define the temperature scale certain fixed points are used which are the temperature-dependent changes of state of certain materials. The two most known fixed points are absolute zero at 0K and the triple point of water (all three phases are present simultaneously) at 273.16 K.

These values make it possible to draw a straight line graph for temperature. Other fixed points were defined for values that are far from these points. For example the triple point of neon at 24.5561 K or the freezing point of silver at 1234.93 K. Thermometers can then be calibrated with so-called fixed point cells. The values of the fixed points are defined in the latest version of the „International Temperature Scale of 1990” (ITS-90) (see Table of Defining Fixed PointsITS-90).

Measuring temperatures correctly

Temperatures can be measured using a wide range of methods. Starting from simple diodes that are found in virtually any electronic circuit for temperature monitoring up to high-precision noise thermometers, Thermometers can be divided into two groups: primary and secondary thermometers.

What are the differences? Primary thermometers are measuring instruments that enable the temperature to be determined without any calibration beforehand to other thermometers. In all cases, physical variables are measured that are linked with temperature by physical relationships. Examples of this are gas thermometers, noise thermometers or the measurement of black body radiation.

This type of sensor is frequently used in special laboratories. These measurements often involve considerable effort and expense. Industrial applications primarily involve the use of secondary thermometers, i.e. sensors that have to be calibrated. In practice resistance thermometers or thermocouples are frequently used. When positioning the measuring device in the process,

one simple but fundamental principle must be observed: The sensor must be installed as close as possible to the point of measurement and should be shielded as much as possible from environmental influences. It is important to understand that the sensor primarily measures its own temperature. Furthermore, this temperature can differ by several Kelvin due to different disturbance variables at the measuring location.

Larger temperature differences between the ambient temperature and the temperature of the medium may result in corrupted values. If the sensor is packed in a thick protective tube, this means that it is removed from the actual measuring point. Temperature changes will only be detected very slowly or with a considerable deviation.

The most important measuring principles

The following measuring methods are used for industrial applications due to their accuracy and suitability further processing the measuring signals:

Resistance thermometers A resistance thermometer measures temperature on the basis of the temperature dependence of the electrical resistance. Pure metals, particularly very pure noble metals have the largest resistance changes. These thermometers are divided into positive temperature coefficient (PTC) resistance thermometers, with a resistance that increases with temperature, and negative temperature coefficient (NTC) thermometers, with a resistance that does the opposite.

If the resistance has a virtually linear characteristic, the temperature value can be calculated simply by using a polynomial equation. Normally, resistance thermometers have a measuring range between -250 and 1000 °C. Important members of this group are standard platinum sensors (e.g. Pt100 with 100 Ω at 0 °C). They are used for accurate temperature measuring up to 850 °C for a wide range of applications.

Thermocouples
A thermocouple consists of two different metals or semiconductors that are joined together. Due to the Seebeck effect, an electrical voltage is produced when there is a temperature difference at the junctions. This thermoelectric voltage (also known as thermoelectric power) is temperature dependent, and varies with metals by a few microvolts per Kelvin of temperature difference.

With this method, the temperature difference is measured between the two junctions (hot junction and cold junction). If the temperature at the hot junction is to be measured, the temperature at the cold junction must be known. In practice the cold junction temperature is measured with a separate temperature sensor. The temperature at the hot junction (measuring point) can be determined on the basis of the thermoelectric series.

Thermocouples are mostly used for measuring temperatures up to 1000 °C and higher. The accuracy depends on precise temperature measurement at the reference junction, however, this method offers a favourable alternative compared to platinum resistance thermometers.

Definitions

Error limits are the maximum deviations from the true value that are guaranteed for a measuring system under specified operating conditions. In comparison to this, measuring uncertainty describes the degree of probability that the stated error limit is not exceeded.

Reproducibility, repetition accuracy
Reproducibility is the maximum deviation of the measured value taken from several measuring series under the same operating conditions.

Resolution
The smallest increment that a measuring device can measure; this is often known as the “digit”.

2-wire circuit
In a two-wire circuit, the conductor resistances are fully included in the total resistance. To determine the true value of the sensor, the resistance RL must be known and compensated for.

3-wire circuit
The three-wire circuit contains a special voltage connection that does not carry a current. In this way, the cables on both sides of the sensor are symmetrical and do not influence the measuring process.

This type of connection is the most commonly used type as it provides compensation without the use of an additional cable and does not require a measuring of the cable resistance.

4-wire circuit
In a four-wire circuit, two cables are used for supplying a constant current at the sensor. The voltage drop across the sensor is then measured with the two other cables that do not carry a current. The effect of the cable resistance is almost completely eliminated. This type of measurement is always required when a particularly high measuring accuracy is required.

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Self heating

In order for the output signal of a resistance thermometer to be measured, a current must flow through the sensor. This measuring current causes a dissipation of power so that heat is generated at the sensor. This will cause a higher temperature to be displayed. In most cases, the device manufacturer fixes the measuring current at 1 mA, which has proved itself to be the most practical value that does not generate any appreciable amount of heat.

State of equilibrium

State of equilibrium	**t_{90}/K**	**t_{90}/°C**
Vapour pressure of helium	3to5	-270.15...-268.15
Triple point of equilibrium	13.08033	-259.3467
Triple point of equilibrium	-17	--256.15
Triple point of equilibrium	20.3	- -252.85
hydrogen Triple point of neon	24.5561	-248.5939
Triple point of oxygen	54.3584	-218.7916
Triple point of argon	83.8058	-189.3442
Triple point of mercury	234.3156	-38.8344
Triple point of water Melting	273.16	0.01
point of gallium Solidification	302.9146	29.7646
point of indium Solidification	429.7485	156.5985
point of tin Solidification	505.078	231.928
point of zinc Solidification	692.677	419.527
point of aluminium Solidification	933.473	660.323
point of silver Solidification	1234.93	961.78
point of gold Solidification	1337.33 |	1064.18
point of copper Soludification	1357.77	1084.62

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