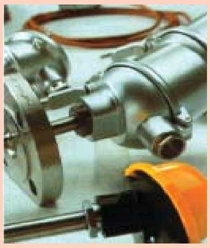
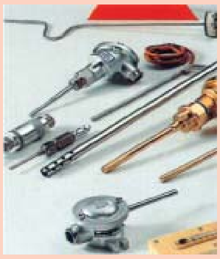
RÖSSEL
MESSTECHNIK





Thermocouples for Industrial Applications

Dipl.-Ing. Reinhard Klemm
RÖSSEL-Messtechnik GmbH

Imprint (ViSdP):
Publisher: RÖSSEL-Messtechnik GmbH
Lohstraße 2; D – 59368 Werne a.d. Lippe
Tel.: +49/(0)2389/409-0; Fax: +49/(0)2389/409-80
Contact: reinhard.klemm@roesselwerne.de

Die Tabellen sind auf der Basis der Polynome berechnet. Für Druck- und Rechenfehler wird keine Haftung übernommen. Im Zweifelsfall gilt grundsätzlich die zitierte Norm.

Bei undatierten Normverweisen ist der Stand zum Zeitpunkt der Veröffentlichung dieser Druckschrift maßgebend.

Issue: April 2009

Table of Contents

Thermocouples for Industrial Applications

1. Introduction

In numerous branches of industry heat-treatment or combustion processes play a decisive role during the production process and in the quality of the final product. Examples are quenching and tempering, hardening or annealing processes. The combustion process is crucial for the quality of ceramics – technical ceramics as well as consumer ceramics like porcelain or for instance tiles.
Many combustion processes are in reality sintering processes – the production of sintered and carbide metals falls into this category.
Not to forget the combustion processes in power plants, waste incineration plants and of course also in combustion engines.
These applications have, however, one thing in common:
In almost all cases thermocouples are used because of the high temperatures involved. Besides thermocouples, which do not contain noble metals (mostly based on iron, nickel or nickel/chromium alloys), more and more those made of platinum/rhodium alloys are being used. For very high temperatures thermocouples made of wolfram/rhenium alloys are used.
These thermocouples must be protected against contaminating, corrosive and/or abrasive effects from the ambient conditions. A wide range of different designs with different protection tube materials is available in this respect.

2. Functional principle of thermocouples

2.1. Thermo-electricity, Seebeck effect, Peltier effect, Thomson effect

This chapter focusses on the application of thermo-dynamical principles on electrical effects, and shows the conversion of heat to electric energy and vice versa. To mention it right at the beginning: heat flow and electron flow are linked to each other directly and inseperably. The one does not exist without the other. This inevitably means that thermocouples only and exclusively can measure **temperature differences.**
These temperature differences are measured by an EMF, which is called "thermo-voltage". On the other hand this thermo-voltage often is an annoying error source for an accurate measuring of smaller electrical values.
In order to eliminate these systemic errors the understanding of thermo-electric effects is essential. There are mainly "only" four effects, which are necessary to understand the functional principle of thermocouples:

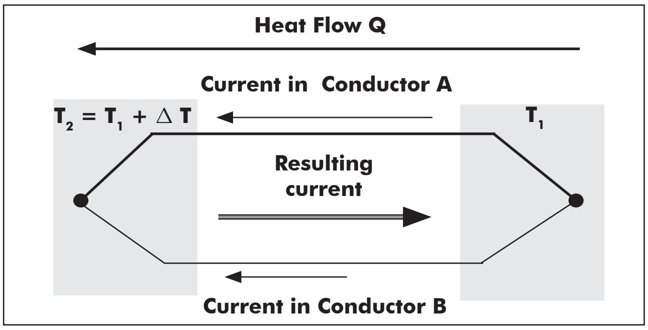


Fig. 1: Schematic illustration of the Seebeck effect

2.2. The Joule effect

In a metallic conductor, through which an electric current flows, Joule heat is generated due to the Ohm resistance → $Q_{Joule} = I^2 \times R$

2.3 The Thomson effect

A chemically homogenous conductor is physically inhomogenous, if a temperature difference (temperature gradient) exists along the conductor. This physical inhomogeneity affects the energetic conditions of the conduction electrons, similar to the chemical inhomogeneity at the contact area between two metals (Seebeck/Peltier effect).
If a temperature gradient occurs at a chemically homogeneous conductor through which current is flowing, there appears a Peltier effect, distributed continuously over the whole conductor, which is called Thomson effect.
One distinguishes between positive Thomson heat (conductor heats up with the flow of current {no Joule heat!}) and negative Thomson heat (conductor cools off with the flow of current). This depends on the direction of the load-independent DC current in relation to the temperature gradient.

2.4. The thermo-electric effect (Seebeck effect)

In a conductor circuit of two different metals an electric DC voltage is generated, if the junctions of the two metals (contact areas) are kept at different temperatures.

In a solid conductor, which is exposed to a temperature gradient, electrical charges shift, an effect, which is called thermal diffusion. The cause for the formation of thermo-electrical fields (thermal electricity) lies – put simply – in the temperature- and thus position-dependent velocity distribution of the charge carriers. Macroscopically measurable effects occur at the combination of differing materials:

If for example two conductors are joined in a loop and if the transitions are heated to different temperatures the thermal electricity appears as a static electrical circuit current (Fig. 1).
It is driven by the so-called thermo-voltage, which in the case of an open circuit, i.e. when there is no current, is also directly measurable (Seebeck effect).
With sufficiently small differences in temperature the amount of the thermo-voltage grows in most cases linear to the temperature differences in the contact areas. At temperature differences of 100 K voltages of up to some mV are typically measured with metal/metal combinations; with doped semiconductors however of up to some 100 mV.
As the thermo-voltage forms due to the thermal diffusion of charges along the conductors the measured values depend greatly on the intrinsic conductive characteristics of the materials being used, i.e. structural defects or contaminations have a big effect at low temperatures.
The Seebeck effect has one important practical application:

The thermo-voltage is a measure for the temperature difference, so that thermocouples can be used as temperature sensors.

The heat dissipation is coupled to the flow of the “free” electrical charge carriers.

A current is thus generated in both conductors due to the Thomson effect.

As material A is not the same as material B the conductor currents are not identical.

This results in a circuit current.

2.5. Conclusions

- The heat dissipation is inseperably linked to the flow of the “free” electrical charge carriers (valence electrons).
- A transport of charge carriers always generates a heat dissipation – and vice versa a heat dissipation generates a charge transport.
- A thermo-voltage is only generated if in a thermocouple of inequal conductors a heat dissipation occurs due to a temperature difference.
- No thermo-voltage is generated in a homogeneous temperature field.
- In a homogeneous conductor the magnitude of the thermo-voltage depends exclusively on the temperature difference between measuring and reference point.
- In the hot junction (welded junction) no thermo-voltage is generated.

2.6. Law of linear superposition

A thermocouple can be seen as a series connection (of an infinite number) of many, differentially small thermocouples, whose thermo-voltages add up linearly.
The polarity of the thermo-voltage depends on the direction of the temperature gradient.

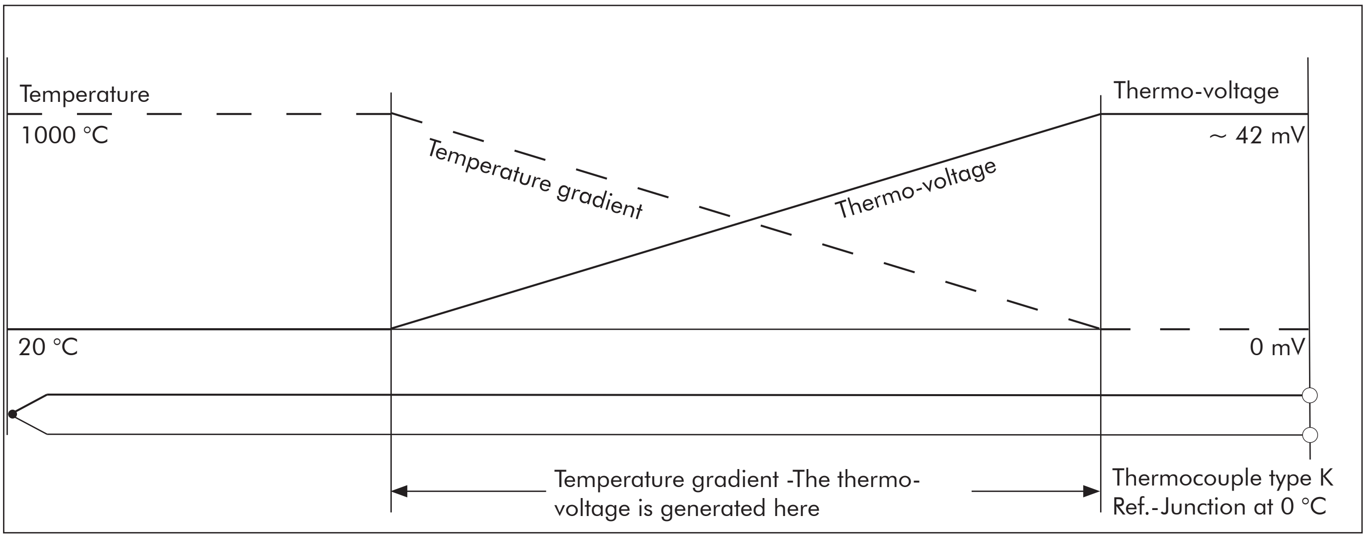


Fig. 2: Schematic illustration of the thermo-voltage characteristics

An additionally applied heating area has no influence, as the additional thermo-voltages cancel each other out mutually.

The generated thermo-EMF at the ends of the conductors is the algebraic sum of all partial voltages. For a given temperature difference it is always equal, independent of the distribution of the temperature gradients.

2.7. The Peltier effect

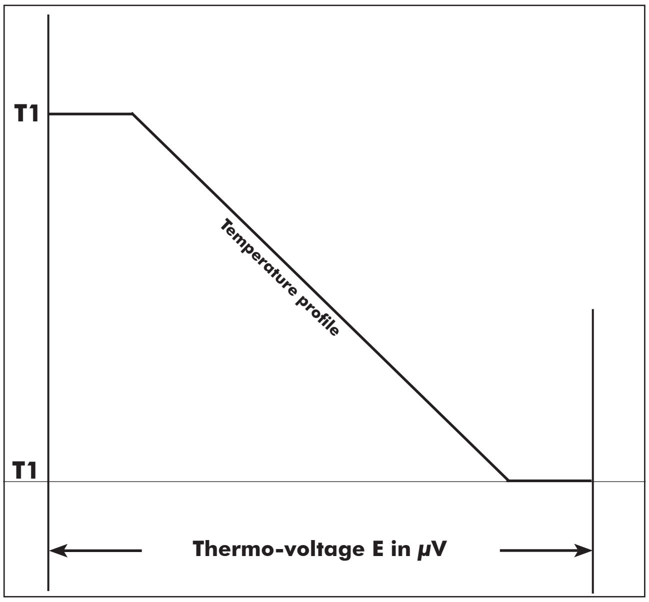


Fig. 3a: Ideal temperature profile

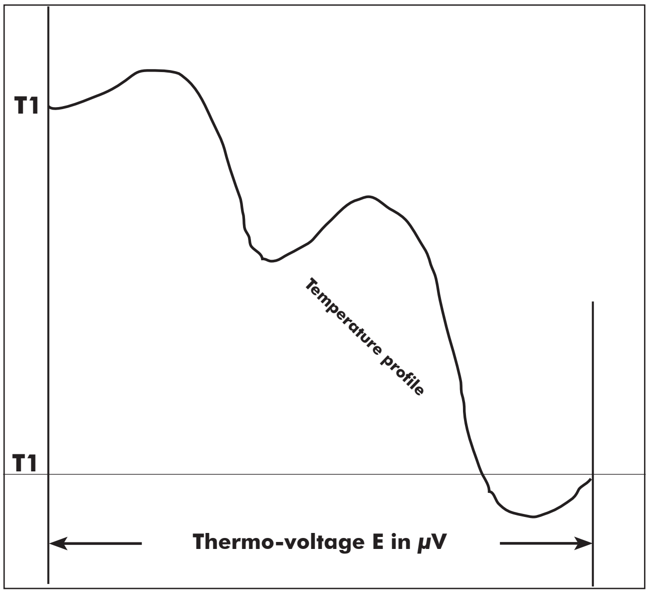


Fig. 3b: Real Temperature profile

Basis for the Peltier effect (Fig. 3) is the contact of two (semi-) conductors, having a differing energy level of the conduction bands. If one runs the current through two contact points of these materials in series, then thermal energy must be picked up at the one contact point for the electron to reach the energetically higher conduction band of the neighbouring semiconductor material, which leads to a cooling-off. At the other contact point the electron drops from a higher to a lower energy level, so that energy in the form of heat is dissipated here (reversal of the thermo-electric Seebeck effect). If one reverses the polarity of the current direction, cooling-off and heating-up are switched. This effect appears also with metals, where however it is very small and where it is almost completely superposed by the current heat and the high thermal conductivity of the metals.

A Peltier element (Fig. 4) consists of two or several small cuboids each of p- und n-doped semiconductor material (bismuth-tellurite - Bi_2Te_3, silicon, germanium), which are connected with each other by metal bridges alternatingly on top and at the bottom. At the same time the metal bridges form the thermal contact areas and are insulated by a foil or ceramic plate. Always two cuboids are connected in such a way that they form a series connection. The applied electric current flows through all cuboids one after the other. Dependent on current intensity and direction the upper junctions cool off, while the lower ones heat up. The current thus pumps heat from one side to the other and generates a temperature difference between the plates.

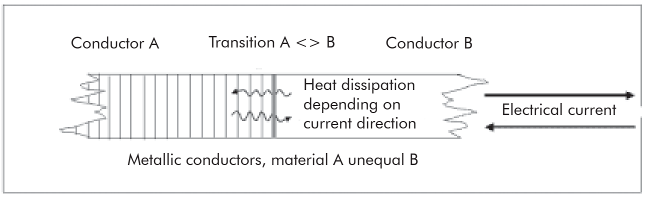


Abb. 4: Peltier effect

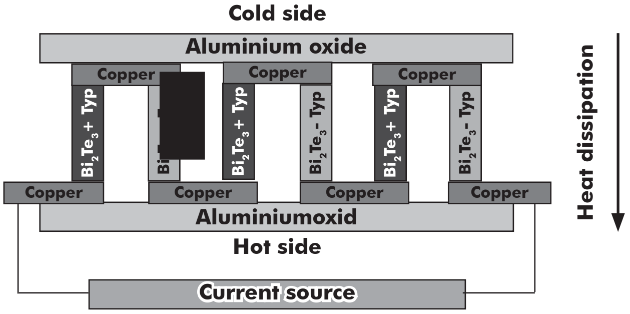


Fig. 5: Schematic illustration of a Peltier element

3. Structure of thermocouple measuring circuits

As already mentioned in chapter "Function principle" a thermocouple can only convert a temperature difference into a proportional thermo-voltage. This correlation is highly non-linear and is mathematically described by a polynomial of higher degree. For the practical application a comparison or reference temperature must additionally be defined, and must also be generated or simulated.

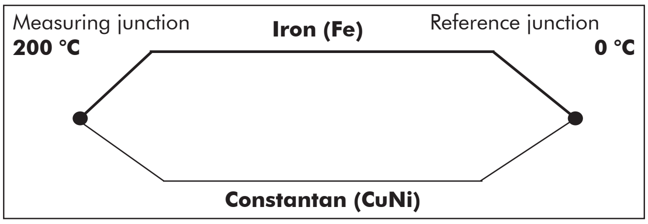


Fig. 6: Basic shape of a thermocouple measuring circuit

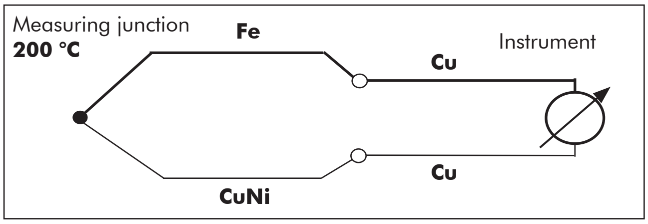


Fig. 7: Thermocouple measuring circuit with instrument

Fig. 6 shows the basic form of a thermocouple measuring circuit. The circuit current generated therein cannot be measured directly. Therefore the measuring circuit has to be split open, and must be connected to a current or voltage measuring unit. Due to the relatively high specific resistance of the thermo materials no current measuring unit is used. Instead a voltage measuring unit with high internal resistance is used, so that the thermo-voltage can be measured with no load.

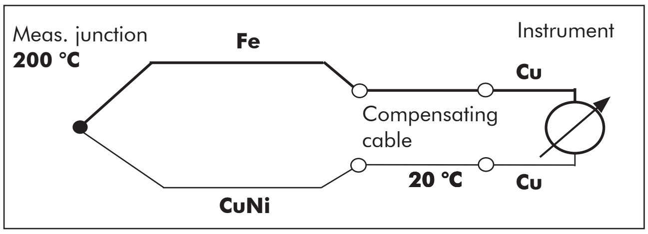


Fig. 8: Measuring circuit with compensating cable

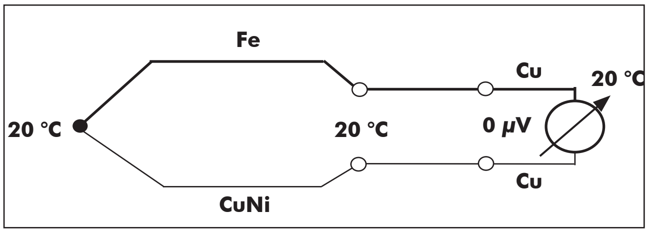


Fig. 9: Zero point of the instrument

Thus a materials transition is inevitably created between the thermo materials and the internal copper conductors of the measuring unit. This transition forms itself as two additional thermocouples and leads to faulty measurements.

As shown in Fig. 9 the measuring unit is to display 20 °C, although the temperature difference is 0 °C and thus the thermo-voltage is also 0 mV. As the ambient temperature (in the above example 20 °C) is normally unknown and by no means stable, a stable and exactly known comparison or reference temperature must be used to obtain reliable measurements.

As highly practicable and easily achievable (ice/water mixture) the cool joint compensation 0 °C has been accepted nationally and internationally.

All values in the tables of standardized thermocouples are based on this cool joint compensation temperature.

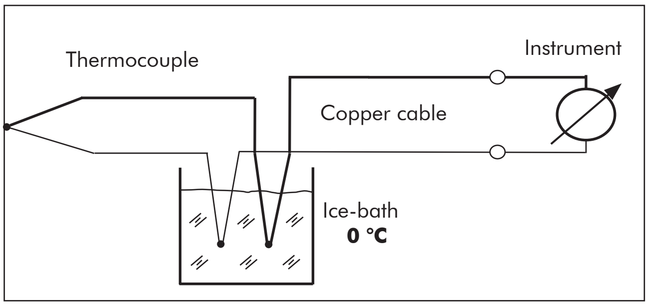


Fig. 10: Classic cool joint compensation

Fig. 10 shows the classical method of the cool joint compensation using an "ice bath" – a mixture of finely minced ice made from destilled water and water also distilled. The advantages of this method: excellent stability, known temperature and easy implementation. Many calibration laboratories are still using this kind of cool joint compensation. However, the fundamental disadvantage is evident: for industrial measurements this method is totally impracticable. There only the simulated cool joint compensation is used.

Fig. 11 shows the analog type of a cool joint compensation.

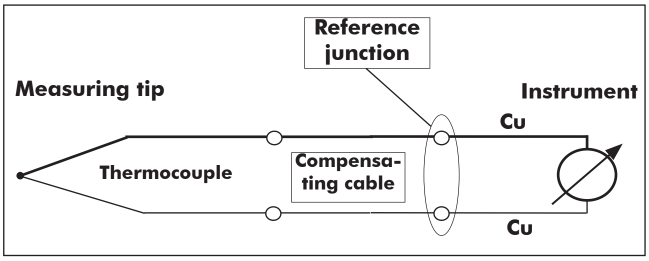


Fig. 11: Simulated cool joint compensation

A sensor measures the temperature of the isothermal block and adds a proportional voltage (in µV) to the input signal. Then the aggregate signal is graphically or electronically linearized and displayed.

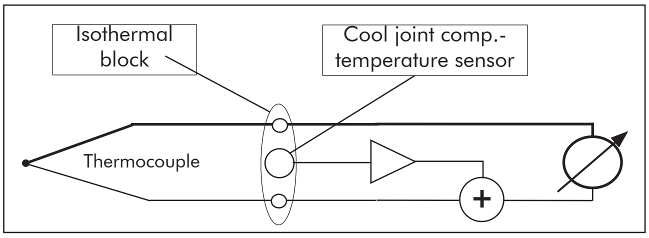


Fig. 12: Analog cool joint compensation

The digital cool joint compensation as per Fig. 13 also uses a sensor to measure the temperature of the isothermal block. This signal is digitalized and added to the also digitalized input signal. The aggregate signal is mathematically linearized and displayed resp. made available for further processing.

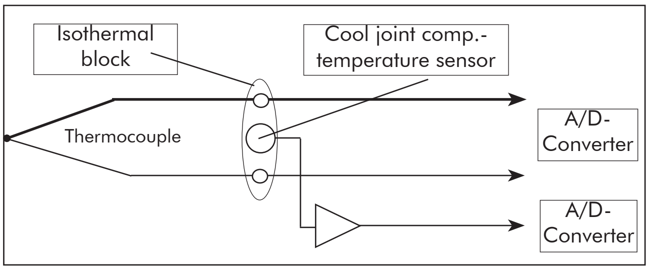


Fig. 13: Digital cool joint compensation

4. Overview of temperature scales, thermocouples and standards

Among the multitude of posssible metal combinations, from which thermocouples can be formed, certain ones were selected and standardized both nationally and internationally.
Combinations of materials were selected, which had proven practical partly for historical reasons and partly for practical technical considerations. Significant criteria for the selection were – besides historical reasons – among others:

- Price and availabilty of the thermo materials
- Stability and repeating accuracy
- Interchangeability
- Wide temperature range

In particular the thermal EMF (nominal thermal EMF), the permitted deviations (also called tolerance or uncertainty of measurement) and the colour-coding were standardized, and not the exact material composition. The following thermocouples have been standardized: Types E, J, K, N, T, S, R and B (see chapter 5.2)

5. Historical overview

The national and international standards which are valid today are of course closely linked to the development of temperature sensors and to the temperature scales accepted internationally as binding. This short historical overview is intended to clarify this:

Historical overview over the development of temperature sensors

1641	First closed liquid thermometer by Ferdinand II, grand duke of Tuscany
1724	First liquid glass thermometer with mercury fill by Daniel Gabriel Fahrenheit
1745	0 to 100 scale based on 2 fixed reference points by Carolus Linnaeus and Anders Celsius
1800	Construction of simple bi-metallic thermometers by A. L. Bréguet
1818	Discovery of the temperature response of the electrical resistance of metallic conductors by H. Chr. Oersted
1821	Description of the thermo-electric effect by T. J. Seebeck
1821	Construction of the first thermocouple by H. Davy
1840	Construction of a thermocouple made of iron (Fe) and nickel silver (CuNi) by Chr. Poggendorf
1852	Establishment of the thermo-dynamic temperature scale, based on the 2nd law of thermodynamics by W. Thomson (Lord Kelvin)
1871	Construction of a Pt-resistance thermometer by W. von Siemens
1885	Further development of the Pt-resistance thermometer into a precision instrument also for higher temperatures by H. L. Callendar
1887	Production of technical thermocouples by H. le Chantelier & C. Barus
1892	Development of the first useable spectral pyrometer by H. le Chantelier

Thus, at the end of the 19th century, practically all electrical contact thermometers and pyrometers still in use today had been invented resp. developed.
Rømer, Newton, Réaumur, Fahrenheit, Delisle, Celsius, Kelvin and Rankine developed already between 1700 and 1860 temperature scales named after them, of which today only the Fahrenheit, Celsius and Kelvin scales are still being used. However, also Poggendorf, Callendar and le Chantelier proposed temperature scales based on fixed reference points with the pertinent standard instruments.

Development of the International Temperature Scales

1889 Callendar proposes three fixed reference points: freezing and boiling point of water as well as the boiling point of sulphur with a Pt-resistance thermometer as standard instrument.

1911 The PTR (later PTB) proposes together with the NPL (England) and BS (later NBS resp. NIST, USA) a thermo-dynamical scale as the first "International Temperature Scale" (ITS).

1913 On the 5th CGPM this scale was to be passed. The imminent outbreak of World War One prevented the conference.

1923 PTR, NPL and BS establish a temperature scale based on fixed reference points (triple point of mercury to boiling point of sulphur) and extrapolated up to 650 °C with Pt-thermometer, as well as up to 1100 °C with thermocouple type Pt10%Rh-Pt.

1925 The scale of 1923 is expanded downwards to -193 °C, and supplemented upwards by the fixed reference points antimony, silver and gold.

1927 The first "International Temperature Scale of 1927" is accepted by the 7th CGPM.

1937 The "Consultative Committee on Thermometry" (CCT) is founded.

1948 The CCT initiates the first revision of the ITS 27 and enacts it as ITS 48.

1958 The 1958 ^{4}He Scale for the temperature range 0.5 to 5.23 K is introduced.

1962 The 1962 ^{3}He Scale for the temperature range < 0.9 K is introduced.

1968 The 2nd revision of the ITS 27 is enacted as IPTS 68. Four sub-ranges are defined:
(a) 13.81 K to 273.15 K; standard instrument: Pt-resistance thermometer
(b) 0 °C to 630.74 °C; standard instrument: same as (a)
c) 630.74 °C to 1064.43 °C; standard instrument: thermocouple Pt10%Rh-Pt and
(d) above 1064.43 °C; standard instrument: spectral pyrometer

1976 The CIPM establishes the EPT 76 for the range 0.5 to 30 K.

1990 The "International Temperature Scale of 1990" (ITS-90) becomes valid world-wide on January 1st, 1990 and replaces IPTS 68 and EPT 76. However the thermocouples are dropped as standard instruments for the approximation of ITS 90 in favour of the Pt-resistance thermometers in the range from 13.8 K (triple point H_2) to 1234.93 K (961.78 °C, freezing point of Ag).

6. The IEC 584-1 (DIN EN 60 584-1) – nominal values of the thermo-EMF

The ITS 90 is presently the world-wide binding temperature scale and thus the basis of the valid standards DIN IEC 60 571 for industrial resistance thermometers and DIN EN 60 584 for thermocouples. In this latter standard eight thermocouples are standardized in two groups:

6.1 Non-noble-metal thermocouples acc. to DIN EN 60 584-1

Ident letter	Description	Meas. range in °C	Thermo-EMF in µV
E	NiCr–CuNi	-200 to 1000	-8825 to 76373
J	Fe-CuNi	-210 to 1200	-8095 to 69553
K	NiCr-Ni	-200 to 1372	-5891 to 54886
N	NiCrSi-NiSi	-200 to 1300	-3990 to 47513
T	Cu-CuNi	-200 to 400	-5603 to 20872

Table 1: Non-noble-metal thermocouples

6.2. Noble-metal thermocouples acc. to DIN EN 60 584-1

Ident letter	Description	Meas. range in °C	Thermo-EMF in µV
S	Pt10%Rh-Pt	-50 to 1768	-235 to 18694
R	Pt13%Rh-Pt	-50 to 1768	-226 to 21103
B	Pt30%Rh-Pt6%Rh	250 to 1820	291 to 13820

Table 2: Noble-metal thermocouples

6.3. Thermocouple type L

Within the area of the “Deutschen Instituts für Normung” (DIN) a standard had existed, in which two types were defined:
DIN 43 710: type L (Fe-CuNi) and
type U (Cu-CuNi)
From their nominal alloy they were identical to the types J and T of DIN EN 60 584, however the nominal thermal EMF differed. The mentioned standard was withdrawn in October 1997. Type L had particularly been used in large numbers in field instrumentation (especially power plants), so that today there still exists a significant demand for this type of thermocouple. Type U has become totally insignificant with the withdrawal of the DIN standard and does not play any role anymore. The following table is thus for information only:

Ident letter	Description	Meas. range in °C	Thermo-EMF in µV
L	Fe-CuNi	-200 to 760	-8166 to 53147

Table 3: Thermocouple type L

6.4. Preview to the revision of IEC 584

Presently a revision of IEC 584 is planned, the “mother standard” of DIN EN 60 584. The Working Group 5 (WG 5 – Temperature Sensors) in the Sub-Committee 65B (SC 65B – Devices & Process Analysis) of the International Electricity Commission (IEC) has been charged with this task.
In Germany the “Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE” (DKE) with its committee K 961 (Electrical Sensors and Transmitters) participates in this work.

On the international level it is planned among other things to add two wolfram/rhenium high-temperature thermocouples to the standard: type C (W5%Re-W26%Re) from ASTM E988 (USA) and type A (W5%Re-W20%Re) from GOST (Russia). Especially type C is gaining increasingly in importance in all fields of industry, where at very high temperatures reducing operational conditions exist. The following table serves as information:

Ident letter	Description	Meas. range in °C	Thermo-EMF in µV
C ASTM 988	W5%Re-W26%Re	0 to 2315	0 to 36931
A GOST 8-585	W5%Re-W20%Re	0 to 2500	0 to 33640

Table 4: High-temperature thermocouples

In the following graph (diagram 1) the generated thermo-voltage of the thermocouples acc. to tables 1 to 4 is shown in relation to the temperature. One can see that the relation between temperature and thermo-voltage is not linear.

This is especially noticeable in the area of negative temperatures. For the linearization and calculation of the values in the table polynomials of higher degree are used. The polynomial coefficients are included in the mentioned standards.

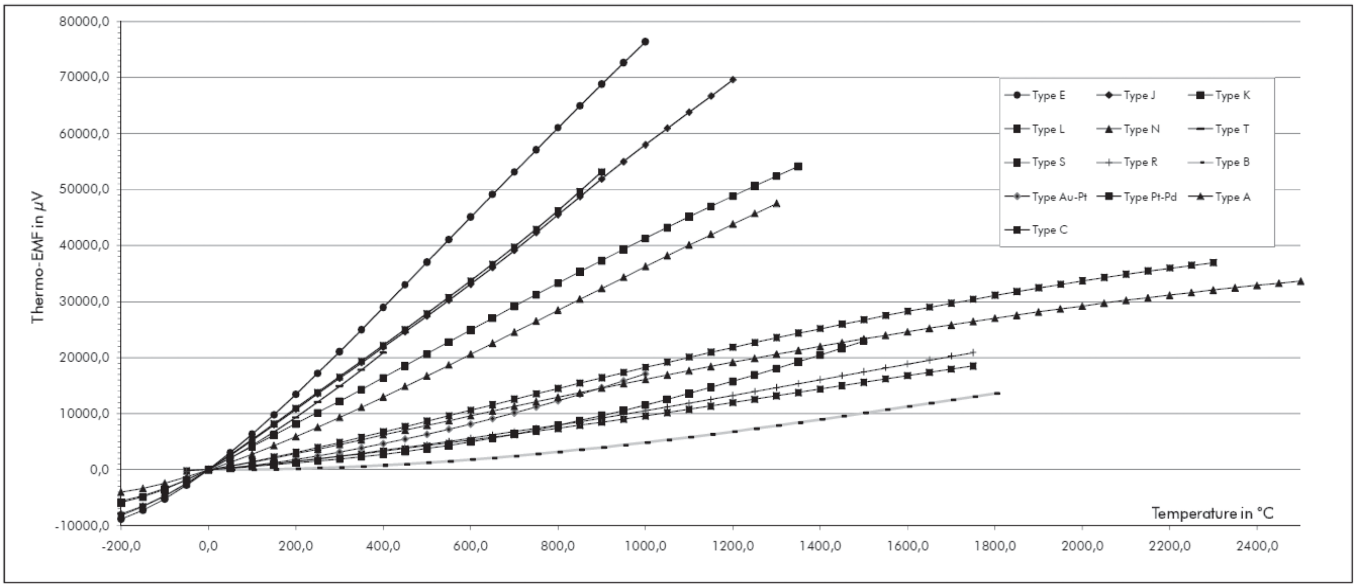


Diagram 1: Thermo-EMF as a function of temperature

In the graph acc. to diagram 2 the specific thermo-voltage (Seebeck coefficient) of the thermocouples acc. to tables 1 to 4 is shown in relation to the temperature. It can clearly be seen that the relation between temperature and thermo-voltage is not linear.

In particular the thermocouples types J, K and L can be described by fractional polynomials only. Type N – in principle a modified type K with higher stability – can be calculated with an integral polynomial.

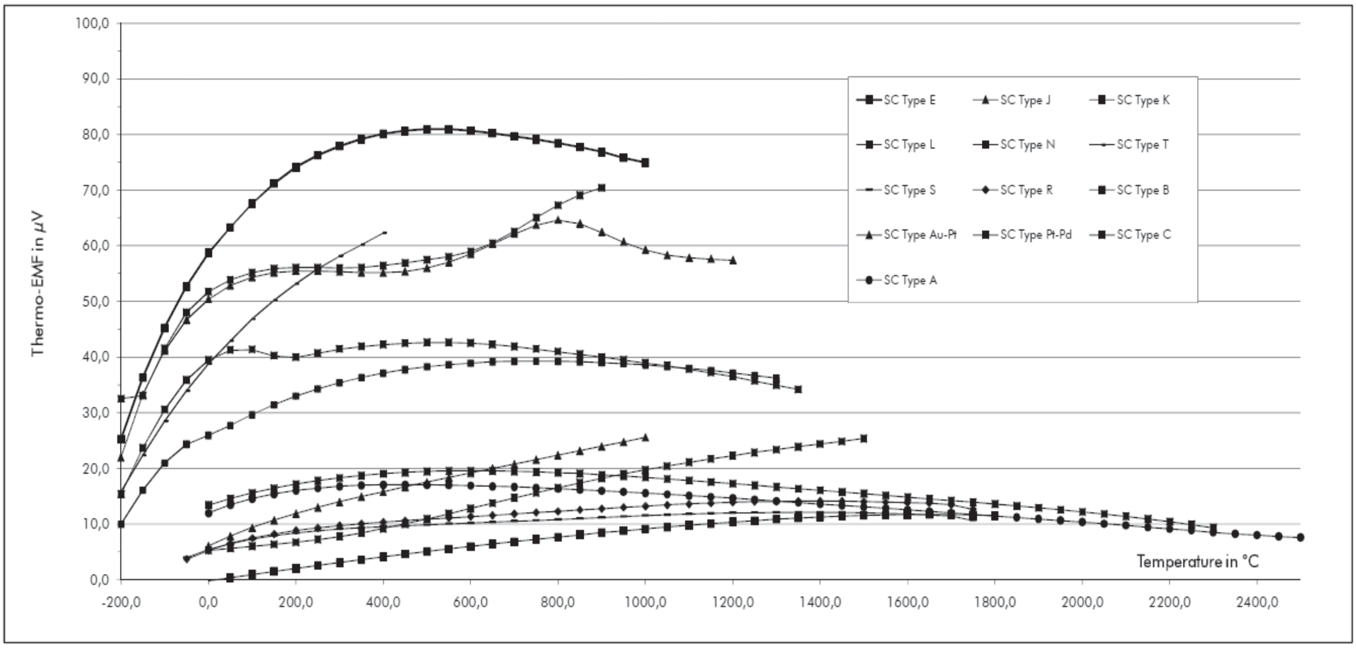


Diagram 2: Seebeck coeffizient as a function of temperature

7. The IEC 584-2 (DIN EN 60 584-2) Permitted deviations

Also the uncertainties of measurement – often called permitted deviations or tolerances – are standardized internationally and nationally. Three classes are defined and for each of these the permitted deviation and the temperature range (scope) are indicated. In industry the classes 1 and 2 prevail as "quasi-"standards. Class 3 is reserved for the relatively rare low-temperature applications.

The permitted deviations shown in the following list for types A and C are inter-nationally so far recommendations only, based on the corresponding national standards. With the revision of IEC 584 these values are to be checked and revised if necessary. The normally available thermo-material meets the stipulated class accuracies (class 1 or 2), but not necessarily also those of class 3. If thermo materials of the types E, J, K, N and T are required, which meet both the tolerances of class 2 and of class 3, then specially selected materials must be used.

	Class 1	**Class 2**	**Class 3**
Permitted deviation	(±) 0,5 °C or 0,004 * [t]	1 °C or 0,0075 * [t]	1 °C or 0,015 * [t]
Type T (Cu-CuNi)	-40 to 350 °C	-40 to 350 °C	-200 to 400 °C
Permitted deviation	(±) 1,5 °C or 0,004 * [t]	2,5 °C or 0,0075 * [t]	2,5 °C or 0,015 * [t]
Type E(NiCr-CuNi)	-40 to 800 °C	-40 to 900 °C	-200 to -40 °C
Type J (Fe-CuNi)	-40 to 750 °C	-40 to 750 °C	---
Type K (NiCr-Ni)	-40 to 1000 °C	-40 to 1200 °C	-200 to -40 °C
Type N (NiCrSi-NiSi)	-40 to 1000 °C	-40 to 1200 °C	-200 to -40 °C
Permitted deviation	(±) 1 °C or [1 + 0,003(t-1100)]	1,5 °C or 0,0025 * [t]	4 °C or 0,005 * (t)
Type S (Pt10%Rh-Pt)	0 to 1600 °C	0 to 1600 °C	
Type R (Pt13%Rh-Pt)	0 to 1600 °C	0 to 1600 °C	
Type B (Pt30%Rh-Pt6%Rh)	---	600 to 1700 °C	600 to 1700 °C
Permitted deviation	---	(±) 0,01 * (t)	---
Type C (W5%Re-W26%Re)		426 to 2315 °C	
Permitted deviation	(±) 0,005 * (t)	(±) 0,007 * (t)	---
Type A (W5%Re-W20%Re)	1000 to 2500 °C	1000 to 2500 °C	

The permitted deviation is given in °C or as a function of the absolute value of the temperature in °C. The larger value always applies.

Table 5: Permitted deviations of thermocouples

8. Permitted deviation of connection cables

In the vast majority of cases the thermocouple is not long enough to bridge the distance between site of installation and indicator. Therefore and also for practical reasons flexible connection cables are needed. Two basic alternatives are available:

Extension cables: flexible cables, which contain thermocouple materials.
These cables have an "X" after the identification letter of the thermocouple; for instance KX or NX. The "X" comes from the English term "extension cable". In some cases the "X" does not appear in the type description.
Compensating cables: flexible cables which contain material similar to thermocouples.
These cables have a "C" after the identification letter of the thermocouple; for instance KC or NC. Compensating cables have thermo-electric characteristics identical to the thermocouple itself only within a closely limited temperature range, and in addition they have wider permitted deviations.
The "C" comes from the English term "compensating cable".

Remarks:

- Compensating cables are available only in class 2 – see following table.
- For types J, T, E and L only extension cables are usual in commerce.
- For the noble-metal types S and R extension cables are available only in exceptional cases due to the high material cost.
- Compensating cables for types S and R contain the same conductor material.
- For type B no compensating cable is specified, used are Cu-cables.
- Thermocouples of class 1, which are fitted with extension cables class 1, normally meet the stipulations of class 1 in toto.

Thermocouples, which are fitted with compensating cables, must not necessarily meet the stipulations of class 1. This remark appears in the ANSI MC 96-1 standard. It is missing in the IEC 584-2 (DIN EN 60 584-2) standard. At the moment this partial standard is being revised among other things with a view to this important aspect.
The following table 6 gives an overview.

Type	Class 1	Class 2	Ambient Temperature	Measuring Temperature
JX	±85 µV (±1,5 °C)	±140 µV (±2,5 °C)	-25 to +200 °C	500 °C
TX	±30 µV (±0,5 °C)	±60 µV (±1,0 °C)	-25 to +100 °C	300 °C
EX	±120 µV (±1,5 °C)	±200 µV (±2,5 °C)	-25 to +200 °C	500 °C
KX	±60 µV (±1,5 °C)	±100 µV (±2,5 °C)	-25 to +200 °C	900 °C
NX	±60 µV (±1,5 °C)	±100 µV (±2,5 °C)	-25 to +200 °C	900 °C
KCA		±100 µV (±2,5 °C)	0 to +150 °C	900 °C
KCB		±100 µV (±2,5 °C)	0 to +100 °C	900 °C
NC		±100 µV (±2,5 °C)	0 to +150 °C	900 °C
RCA		±30 µV (±2,5 °C)	0 to +100 °C	1000 °C
RCB		±60µV (±5,0 °C)	0 to +200 °C	1000 °C
SCA		±30 µV (±2,5 °C)	0 to +100 °C	1000 °C
SCB		±60 µV (±5,0 °C)	0 to +200 °C	1000 °C
CC		±110 µV (±9 °C)	0 to +871 °C	2000 °C
AC		±110 µV (±11 °C)	0 to +871 °C	2000 °C

Table 6: Permitted deviations for connection cables

Remarks:

The indicated ambient temperature refers to the conductor material used. The temperature range of the insulation materials of the cable may differ in some cases!
For type B a copper cable is used in the ambient temperature range 0 to 50 °C. The expected additional uncertainty of measurement is max. ± 10 µV (± 5 °C) at a measuring temperature of 1400 °C. In the range 0 to 100 °C this amounts to ± 40 µV (± 3.5 °C) at the same measuring temperature.
The tolerances are given in µV. The temperatures in brackets are valid due to the non-linear relation between temperature and thermo-voltage only for the given measuring temperature. In most cases the error is higher at considerably lower or higher measuring temperatures.

8.1. IEC 60 584-3
Colour-coding

At the end of this rather dry chapter on temperature scales, thermocouples and standards just a few words on the colour-coding of thermocouples, in particular extension and compensation cables. As the thermo-voltage is a DC voltage, the polarity of the cables must be clearly identified. In addition to a number of national standards an international standard – IEC 584-3 – is available since December 2008.

Ident letter	+ Pole	- Pole	Sheath
E	purple	white	purple
J	black	white	black
K	green	white	green
L	red	blue	blue
N	pink	white	pink
T	brown	white	brown
B	grey	white	grey
R	orange	white	orange
S	orange	white	orange
A	red	white	red
C	yellow	white	yellow

Table 7: Colour-coding

Remarks:

- The colour-coding for type L is from the withdrawn standard DIN 43 714, but it is still being used.

- The colour-coding for thermocouples acc. to DIN EN 60 584 is regulated in DIN 43 722 and corresponds to IEC 60 584-3.

- The colour-coding for types A and C are recommendations so far and are based on national standards.

9. Industrial designs examples

Two designs mainly have prevailed as regards industrial designs:

straight thermocouples DIN EN 50 446 and

sheathed thermocouples DIN EN 61 515.

9.1. Straight thermocouples with metal or ceramic protection tube

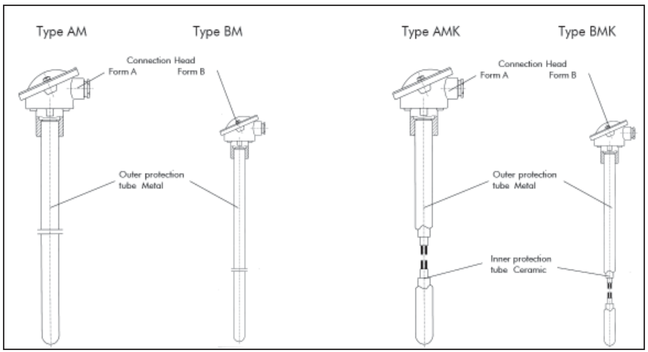


Fig. 13: Straight thermocouples with metal protection tube

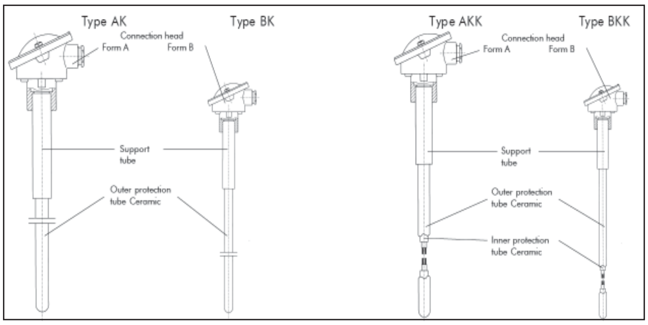


Fig. 14: Straight thermocouples with ceramic protection tube

Straight thermocouples consist mainly of the following components:

- Connection head for the connection of the extension or compensation cables

- Metal or ceramic protection tube, if necessary with ceramic inner protection tube (tables 8/9)

- Metal mounting tube – only with designs with ceramic protection tube

- Ceramic multihole insulation rod with thermocouple (table 10)

The connection heads are preferably of aluminium, only rarely of plastic (polyamide), stainless-steel or grey cast iron. Two sizes (Form A and Form B) are available. In many cases a transmitter is mounted into the connection head.
The metal or ceramic protection tubes form a "fire wall" for the thermocouples against the often harsh operating conditions resp. process atmospheres. As protection tube materials several different materials are available.

Table 8 gives a brief overview of the materials mostly used. In addition there is a wide range of special materials for often very special applications. If noble-metal thermocouples in metal protection tubes are used, then normally a ceramic inner protection tube is used as a protection against contamination and metal ions. A ceramic protection tube is to be recommended in general for applications in a higher temperature range.

The ceramic protection tube is cemented with a special ceramic putty into the metal protection tubes (st/st material no. 1.4571). Several different materials are available. Table 7 gives a brief overview of the materials mostly used.

The thermocouples (table 10) are inserted into the ceramic insulation rods – also called capillary rods. All standardized types are being used. Because of scaling and life expectancy larger wire diameters (1.0 – 1.38 – 2.0 and 3.0 mm) are used in most cases with non-noble-metal thermocouples.

With noble-metal thermocouples smaller wire diameters (0.5 resp. 0.35 mm) are used for cost reasons. A ceramic connector socket is also fitted to the connection side. Insulation rods with 2 to 16 capillaries for 1 to 9 thermocouples are standard.

As ceramic materials the types C 610 for non-noble-metal thermocouples and C 799 for noble-metal thermocouples are used.

Ident letter	Name or Shortname	Material No.
BF	St 35.8	1.0305
DU	X 18 CrNi 28	1.4749
R	X 10 CrAl 24	1.4762
D	X 15 CrNiSi 2520	1.4841
Y)1	Incoloy 800	1.4876
CS)1	Kanthal Super	---
B	X 6 CrNiMoTi 17-12-2	1.4571
N)1	Molybdenum	---
O)1	Tantalum	---
)1 Different diameter		

Table 8: Ident-letter for metal protection tubes

Ident letter	Material acc. to DIN 40 685 Part 1 VDE 0335 Part 1
CX	C 530 (K 530)
CY	C 610 (K 610)
CZ	C 799 (K 710
RSiC)1	Siliconcarbide, recrystallized
SiSiC)1	Siliconcarbide, reaction-bonded
)1 Different diameter	

Table 9: Ident-letter for ceramic protection tubes

Ident letter	Thermocouples acc. to DIN EN 60 584 ASTM 988 and GOST 8-585
E	NiCr - CuNi
J	Fe - CuNi
K	NiCr - Ni
N	NiCrSi - NiSi
S	Pt10%Rh - Pt
R	Pt13%Rh - Pt
B	Pt30%Rh - Pt6%Rh
L)1	Fe - CuNi
C (W5)	W5%Re - W26%Re
A (A1)	W5%Re - W20%Re

)1 Standard withdrawn 07/97

Table 10: Ident-letter for thermocouples

The following table gives an overview of protection tubes and applications:

Material	Max. operat. temp. °C	Characteristics/Applications	Remarks
Titanium	600	Quenching bath	Heavily oxidizing in air
Pure iron 1.1003	900	Salpetre-, chloride-, cyanide containing salt baths	
Steel, enamelled	600	Molten zinc	
1.0305	900	Annealing furnace, Salpetre baths up to 500 °C, molten babbitt metal, lead- and tin up to 650 °C	In case of lead oxide with hard-chromium coating
1.4571	800	Good chemical resistivity	Largely acid resistant
1.4762	1200	High resistivity against sulfurous gases (oxidizing and reducing), medium resistivity against carburisation	
1.4749	1100	Molten lead and tin, annealing and quenching ovens with sulfurous and carbonaceous gases	
1.4772	1250	Molten copper and brass	
1.4821	1350	Salpetre-, chloride-, cyanide containing salt baths	
1.4841	1200	Cyanogen bath up to 950 °C, molten lead up to 700 °C; furnaces with nitrogenous, low-oxigen gases	
Cast iron (GG 22)	700	Molten babbitt metal, lead-, aluminium and zinc	
GG with ceram. coating.	800	Molten aluminium and zinc	
Cr-Al-Oxide $CrAl_2O_3$ 77/23	1200	Gas-tight, oxidation-resistant, temperature shock resistant, molten copper, tin, zinc, magnesium, lead, cement furnaces, SO_2-, SO_3-gas, H_2SO_4-acid	Not for molten Al, glass and salt baths
Molybdenum-disilizide $MoSi_2$	1700	Abrasion- and shock-resistant, highly temperature shock-resistant, surface-glazed, chemically resistant, waste incineration, fluidized bed combustion	Brittle at low temperature, above ~1400 °C viscid
Molxbdenum-zirkonium-oxide MoZrO 60/40	1700	Abrasion- and shok-resistant, molten cast-iron-, copper, zinc and others, BaCl - quenching baths	Oxidiert in Luft ab 500 °C
C 530	1500	All kinds of gases with form AKK, temperature shock-resistant	Gas-tight inner prot.-tube in straight thermocouples
C 610	1600	All kinds of gases with form AKK, less temperature shock-resistant than C 530	Gas-tight inner prot.-tube in straight thermocouples
C 799	1600	All kinds of gases, contact with hydrofluoric acid-, metal-oxide- ans alkaline gases, molten glass	Molten glass with Pt-coating
Silicon-carbide SiC, recrystallize	1300	Gas-tight, mechanically highly resilient, highly temperature shock-resistant, high thermal conductivity, 8 – 12 % free silicon	Not for molten Al and Cu
Silicon-carbide SiC, reaction-bonded	1600	Porous, mechanically highly resilient, high thermal conductivity, suitable under protection gas or vacuum up to 2000 °C	Not for molten Al, Cu, Ni, Fe, medium temperature shock-resistant
Silicon.nitride Si_3N_4	1000	Temperature shock-resistant, no wetting in molten aluminium or brass	Shock-sensitive
Silicon-nitride/aluminium-oxide $Si_3N_4 + Al_2O_3$	1300	Temperature shock-resistant, molten aluminium or brass	
Graphite	1250	Oxigen-free molten copper, brass and aluminium	High oxidation in air
Aluminium-titanate Al_2TiO_5	1000	Gas-tight, molten aluminium	Shock-sensitive
Sapphire	2000	Mono-crystalline aluminium-oxide, gas-tight, transparent, semiconductor industrie	Schlagempfindlich, mittlere Thermoschockempfindlichkeit

Table 10: Protection tube materials

The table above does not claim to be complete and comprehensive. All remarks are given without liability and do not constitute guaranteed characteristics.
They must be checked and verified in detail with regard to the specific application.

10. Mineral insulated thermocouples

Mineral **I**nsulated **M**etal **S**heathed (MIMS) thermocouples were successfully introduced many years ago into temperature measurement technology. The standard versions are mainly used in the range between -270 °C and +1200 °C. They combine the advantages of high flexibility and easy handling in an extremely wide temperature range.

They are supplemented by high-temperature MIMS thermocouples for operating temperatures of 2000 °C and above.

Inconel 600 is mainly used as sheath material, a nickel-based alloy. This material can easily be welded and soldered, it possesses extremely good resisitivity characteristics also at higher temperatures, and is resistant against most ambient conditions.

The thermocouple is often the type K (NiCr-Ni) acc. to EN 60 584 (DIN IEC 584). Widely in use are also types L resp. J (Fe-CuNi), and in the higher temperature range the precious metal types S, R and B, which are platinum/rhodium alloys

The thermocouple wires are embedded in a compact insulation of high-purity MgO, and enclosed by a metal sheath of a nickel/chromium/iron alloy or of stainless steel. The compact insulation fixes the wires securely so that no damage can occur because of strong vibrations or high bending loads. Also short circuits between the wires or between wire and sheath are virtually impossible.

Sheathed thermocouples (also called Mineral Insulated Metal Sheathed – “MIMS” thermocouples) are produced in very large quantities.
They cover practically all areas of application. They are used as measuring inserts (DIN 43 735) for protection tubes (also called thermowells) acc. to DIN 43 772 in the chemical industry and in power plants as well as in the above described straight thermocouples.

Their important strength is that sheathed thermocouples cover in small steps the range of outer diameters from 0.25 mm to 10.0 mm. Their length can – depending on the outer diameter – vary between a few millimeters to 10 meters and more. Besides sheathed thermocouples with only one thermocouple also designs with 2 and 3 thermocouples are available.

MIMS thermocouples are highly robust temperature sensors. They are easy to handle, highly flexible and almost not affected by vibrations.
They are used in the automotive industry, in power plants, refineries, smelting plants, in ship-building, in the chemical industry, at and in combustion engines, engine testing plants, gas and steam turbines, in medicine, at forges and foundries, in the iron and steel industry, in aeronautics, vacuum and high-vacuum plants, in pressure-sintering plants for carbides, etc.

The good heat transfer between metal sheath and thermocouple guarantees short response times (t0.5 from 0.15s) and a low uncertainty of measurement. The smallest bending radius is 5 to 7 x the outer diameter. The minimum insertion length should not be less than 20 x the outer diameter, at least however 50 mm.

A multitude of different designs is available. Following is an overview of the types mainly used. In addition to that special designs can be produced in most cases.

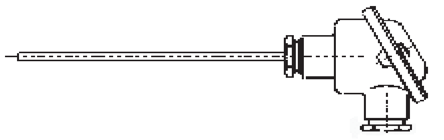
In this AL-design the connection cable is hard-wired. The transition sleeve has a diameter of 6 or 8 mm, depending on the type of cable. The standard length is 5 mm. The cable type (conductor cross section, insulation structure, screening) can be chosen from a wide range.

With type S the connector system is directly connected to the MIMS thermocouple. The standard version is fitted with a jack type RLK, size 0 (up to 1.6 mm sheath diameter, above that size 1). The pin is the positive pole. The brass contacts are galvanically gold-plated.

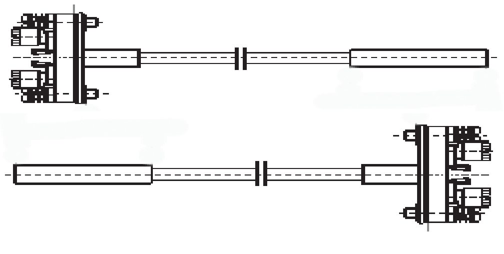
With type STE the plug is directly connected to the MIMS thermocouple. The standard version is fitted with a miniature plug (thermocouple dia. </= 1.6 mm) resp. with a standard plug. The contacts are made of thermocouple material, the outer body of temperature-resistant plastic material.

Type ALSTE adds one thermocouple plug to form AL. Depending on customer specification this type is fitted with a miniature resp. standard plug. The contacts are made of thermocouple material, the outer body of temperature-resistant plastic material. The permitted plug and sleeve temperature depends on the type of cable.

Type ALS adds one circular LEMO jack to form AL. This version is equipped, depending on customer specification respectively cable diameter, with a round jack size 0 or size 1. Other sizes are available on request.
The brass contacts are gold-plated. The brass outer body is matt-chromium-plated. The plug and sleeve temperature depends on the type of cable.



This design consists of a measuring insert with connector socket and cable clips, fitted into a connection head form B acc. to DIN 43 729. A special pipe screw joint holds the measuring insert firmly in place. The nominal length starts at the bottom edge of the pipe screw joint. Other connection head designs are available on request.



Measuring insert with connector socket, cable clips and spring-loaded pressuring device. Suitable for mounting in connection heads form B acc. to DIN 43 729.
Versions:

A. Sheath diameter constant 3.0 mm
B. Sheath diameter constant 6.0 mm
C. Sheath diameter 6.0 mm, measuring tip reinforced 8 mm dia. and 50 mm long
B. Sheath diameter constant 8.0 mm

11. Response time and insertion lengths

The response time of a contact thermometer indicates how fast the thermometer responds to an abrupt temperature change. The VDI/VDE recommendation “Response times of contact thermometers” deals intensively with this topic and shows the schematic design of instruments to measure the response to the jump in temperature.

The response behaviour of a temperature sensor is described by an exponential function. The sensor (and the medium surrounding it) should at first be at the temperature T1. Then the temperature of the medium changes abruptly to T2. The sensor accepts this value only with a time delay. The time-dependent curve of the measuring signal represents the transfer function. Two values have been chosen to characterize the function: $t_{0.5}$ and $t_{0.9}$. This is the time after which the measuring signal reaches 50 %, the so-called half-life time, resp. 90 % of its final value. Fig. 15 illustrates this function.

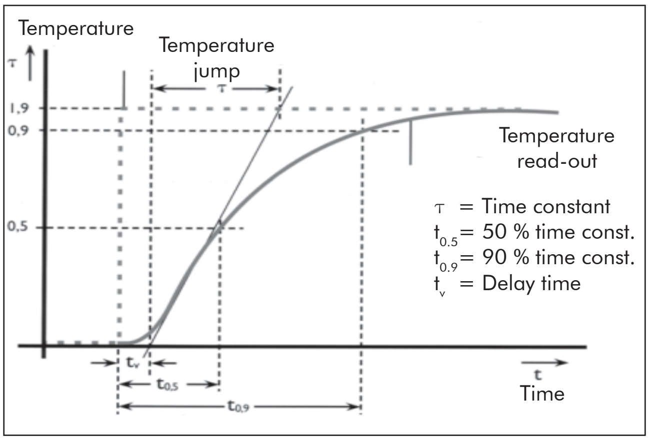


Fig. 15: Response time

Reference values for the response time of contact thermometers. These are based on the following parameters:

- Laminar air flow at 2 m/s
- 10 … 15 °C temp.-jump from room temp.
- Laminar water flow at 0.2 m/s
- Temp.-jump from approx. 25 °C to approx. 35 °C
- Standard air pressure at 1013 hPa

Reference values for the response time of sheathed thermocouples in seconds (-5 % / +15 %)

Conditions	Time	Junction ungrounded Sheath diameter in mm						
	sec.	0.5	1.0	1.5	3.0	4.5	6.0	8.0
Water 0,2 m/s	50 %	0.06	0.15	0.21	1.2	2.5	4.0	7
	90 %	0.13	0.5	0.6	2.9	5.9	9.6	17
Air 2 m/s	50 %	1.8	3	8	23	37	60	100
	90 %	5.9	15	25	80	120	200	360

Table 11: Response time

Remarks:

The response times for thermocouples, where the measuring tip is welded to the sheath (grounded types), are shorter by 10 … 15 %.
Resistance thermometers have a response time of approx. 15 … 25 % longer than similar constructed thermocouples.

11.1. Insertion lengths and heat dissipation faults

A temperature measurement with a contact thermometer is always subject to a systemic heat dissipation error. It can only be minimized – but never be eliminated.
The following tables show the recommended insertion lengths for temperature sensors with and without protection tube.

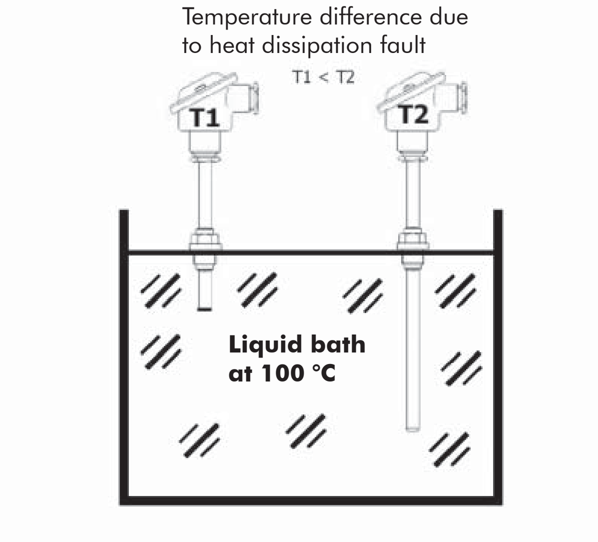


Fig. 16: Heat dissipation fault

Insertion length = medium contacted length.

In real industrial plants these installation conditions can however not always be met. When undershooting the insertion lengths measuring errors due to heat dissipation (heat-dissipation errors) must be taken into account.
The quantitative size of the errors depends on the given installation conditions, on the design of the sensor, the wall thickness of the protection tube, on the medium etc., and can thus in most cases only be estimated.

If adequate laboratory conditions are available the magnitude of the heat-dissipation error can also be determined quantitatively. The transfer of the results to the conditions in industry can sometimes pose unexpected difficulties.

The following table offers guidelines for the recommended immersion depth of MIMS thermocouples.

	Sensor diameter in mm		
	1.5 / 1.6	3.0 / 3.2	5.0 / 6.0
Medium	**Min. insertion length in mm)1**		
gaseous)2	22 ... 30	45 ... 60	75 ... 120
liquid)2	8 ... 15	15 ... 30	25 ... 50
solid)3	8 ... 12	15 ... 20	20 ... 30

Table 12: Insertion length

[1]): With resistance thermometers the length of the measuring resistor (type-dependent 15 … 30 mm) must be added to the values in the table

[2]): Higher value → stationary medium,
lower value → flowing medium

[3]): Higher value → narrow-tolerance bore,
lower value → soldered into the mounting bore

As a general guideline of the thumb the following formulas can be applied:

Minimum insertion length = 15 ... 20 times the outer diameter in gasses

Minimum insertion length = 5 ... 10 times the outer diameter in liquids

12. Ageing, drift and inhomogeneities

Temperature sensors are submitted during their intended use to an operation-related, inevitable change! This change is not reversibly.

This highly complex process is often summarized under the term “drift” or also “ageing”. The long-term behaviour (long-term stability) of a temperature sensor under operational conditions is the result of a number of factors.
These factors can be of a metallurgical, chemical or physical nature, or of a combination of these factors. It is practically impossible to predict the drift process of a temperature sensor in given operational conditions.
Put roughly there are three main areas of causes for drift:

- Mechanical changes of the thermometer or the sensor
- Metallurgical changes of the sensor material due to changes in the crystal structure
- Metallurgical changes of the sensor material due to contamination

The most important forms of mechanical changes are sharp bends in excess of the permitted minimum bending radius, high process pressures as well as abrupt temperature changes – in particalur fast cooling-off speeds.

Metallurgical changes of the sensor materials due to changes in the crystal structure occur in practically all two- or multi-material alloys. Well known is the so-called K-effect (short range ordering effect) with thermocouples type K. It causes an inhomogeneity of the thermocouple. But also all other thermocouples, which do not contain noble metals, and where one leg consists of a NiCr alloy, more or less show this effect. Even with PtRh thermocouples this effect exists – very small, but provable.
With WRe thermocouples a re-crystallization process in the leg with the lower alloy is very high during the first heating periods above approx. 1280 °C. It leads to a permanent change and can amount to 0.4 % of the measured value.

A metallurgical change of the sensor material due to contamination is one of the most frequent causes for drift.
For the thermo-voltages of the thermocouples to meet the normative default values the alloys resp. the purity of the thermo-wires must be adhered to rather strictly. The thermocouples react in general very sensitively to metallurgical contaminations, which change the alloys in their composition.

Contaminations in the area of but a few ppm can – depending on the thermocouple – lead to significant deviations from the nominal thermal EMF. Thermocouples, where one leg consists of a pure metal, react especially sensitive to contaminations. These foreign materials can originate from the sheath material, the protection tube material, the insulation ceramics or the process medium.

But also the two legs of a thermocouple affect each other at higher temperatures through diffusion mechanisms – for instance at the junction point (welding point, also called thermo-knot). Well known is the rhodium diffusion in PtRh thermocouples over the welding area.

The following table 13 shows the influence of several typical contaminations on the thermo-voltage of a thermo-wire of pure platinum (purity > 99.99 %).

Element	**dU_{th} in µV/ppm**
Fe (Iron)	2,30
Ni (Nickel	0,50
Ir (Iridium)	0,35
Mn (Manganese)	0,32
Rh (Rhodium)	0,20
Cr (Chromium)	0,12

Element	**dU_{th} in µV/ppm**
Cu (Copper)	0,07
Pd (Palladium)	0,03
Ag (Silver)	-0,07
Au (Gold)	3,00
Pb (Lead)	4,04
Si (Silicon)	~ 20

Table 13: Contamination

12.1. Frequent cases of contaminations

- Pure materials like Fe, Cu and Pt drift due to the diffusion of impurities. Noble metals react stronger than non-noble metals.

- Strong Pt toxins are Si and P. Si changes Pt to a brittle alloy with a melting point of 1340 °C. P causes extreme brittleness and the decay of the wire at temperature changes.

- With Pt thermocouples rhodium diffusions occur over the measuring tip → measuring error with temperature gradients.

- Two-material alloys tend to initial drifts due to the annealing of grid strains and defects.

NiCr legs react sensitively to the diffusion of sulphur and hydrogen.

- The thermocouples types K and N show a comparatively low drift resp. contamination, as both legs drift in the same direction and their sums practically cancel each other out thermo-electrically.

I would finally like to mention the selective chromium oxidation.
It occurs mainly in NiCr alloys under low-oxygen or reducing atmospheres in connection with humidity in the temperature range from approx. 800 to 1000 °C.
The humidity can form from the diffusion of hydrogen and reduced metal oxide – the insulating material on the inside of the MIMS thermocouple. The water is dissociated on the hot metal surface into hydrogen and oxygen.
The conductor depletes of chromium through the formation of chromic oxide, as a stabilizing "skin" of nickel-oxide is reduced to nickel-hydride. Depending on the temperature/pressure ratio nickel-hydride can be gaseous. It diffuses in the direction of the cold end of the thermocouple and disintegrates there into metallic nickel.
The measuring point kind of "travels" to the cold end, which can lead to a measuring error of up to several 100 K.

12.2. Summary

Drift: A change of the reading or of a set value over a long period of time due to various factors, like for instance changes in the ambient conditions, changes of the operational conditions, ageing of components, ageing of the sensor, contaminations, etc.

Result: The measuring result gets more and more inaccurate with time, as the course of the drift is not foreseeable and therefore not known. In particular the ageing of thermocouples is incalculable!

Important factors which can lead to drift (ageing) of electrical contact thermometers:

- High permanent operating temperature
- Rapid temperature changes
- High cooling-off speeds
- Contamination through process media
- Decay through process media
- Contamination due to metal/ions diffusion
- ....

Also when used as intended a drift of the sensor cannot be avoided!

13. Final remarks

As already shown in chapter 5 the development of contact temperature sensors ended in principle towards the end of the 19th century. The non-contact temperature measurement began however only around 1890. Nowadays it is gaining more and more in importance compared to contact thermometers.

Already at the start of the 18th century there existed efforts to establish uniform criteria – scales – for the measurement of temperature. Even today, in the 21st century, these efforts still continue – even though today the discussion is about milli- and micro-Kelvin.

The mere development of temperature sensors lasted for about 250 years. In the approximately 110 years thereafter until today temperature became the most frequently measured unit. The thermocouples play a decisive role here – they have a share of approximately 60 % of the production and application numbers.

The functional principle of temperature sensors has basically not changed since the beginnings in the 17th century. The apparent disadvantage that the electric measuring value of thermocouples is in the range of a few millivolts has been more than compensated by the instrument technology available today.

The possibility to adapt especially thermocouples almost without problems to practically any industrial measurement task makes them a nearly ideal sensor.

14. List of literature

Fischer, H.: „Werkstoffe in der Elektrotechnik", 3. Auflage, Carl Hanser Verlag, München/Wien 1987

Michalowsky, L: „Neue Technische Keramikwerkstoffe", Wiley-VCH-Verlag 1994

Bergmann, W.: „Werkstofftechnik", Teil 2, Carl Hanser Verlag, München / Wien (1987

Kittel, Ch.: „Einführung in die Festkörperphysik", Oldenbourg-Verlag, München / Wien 1970

Philippow, E.: „Grundlagen der Elektrotechnik", 9. Aufl., Verlag Technik, Berlin / München 1992

Beckerath, A. von u.a.: WIKA-Handbuch „Druck- und Temperaturmesstechnik", ISBN 3-9804074-0-3

Alfa Caesar, A.: Johnson Matthey Company „Forschungschemikalien, Metalle und Materialien 1999-2000"

Weber, D.; Nau, M.: „Elektrische Temperaturmessungen", M. K. Juchheim, Fulda, 6. Auflage. Nov. 1997

Körtvelyessy L.V.: „Thermoelement Praxis", Vulkan Verlag, Essen 1987

Weichert, L.: „Temperaturmessung in der Technik", Expert Verlag, Sindelfingen 1992

Lieneweg, F.: „Handbuch - Technische Temperaturmessung", Vieweg Verlag, Braunschweig 1976

Autorenkollektiv VDI Berichte 1379, „Temperatur 98", VDI Verlag GmbH, Düsseldorf 1998

VDI/VDE-Richtlinien 3511 „Technische Temperaturmessungen", Blatt 1-5, Düsseldorf 1993

Bonfig, K.W. u.a.: „Technische Temperaturmessung", Veranstaltungsunterlagen, Haus der Technik e.V., Essen, 1999

Die vorstehende Liste erhebt keinen Anspruch auf Vollständigkeit. Wegen der unübersichtlichen Vielzahl der Veröffentlichungen zum Thema wurde eine mehr willkürliche Auswahl getroffen. Sollte eine wesentliche Veröffentlichung, zitiert oder nur erwähnt, nicht aufgeführt sein, bitten um Nachsicht. Bitte informieren Sie uns entsprechend, damit wir die Liste vervollständigen können.

TC's
RTD's
Accessories
Transmitters
DKD-Calibrations

- High-temperature thermocouples up to 2300 °C
- Profile and multipoint thermocouples
- Special designs to customer specifications
- MI thermocouples (ATEX)
- Thermocouple measuring inserts (ATEX)
- MI resistance thermometers (ATEX)
- Resistance thermometer measuring inserts (ATEX)
- Measuring resistors

- Calibration instruments and systems
- Calibrators and simulators
- Vendor certificates
- Calibration laboratory DKD-K-09701for temperature www.centrocal.de and www.dkd.info/de/_laboratorien.htm

- Digital transmitters (EEx(i), HART)
- Analog transmitters (EEx(i))

- Protection tubes acc. to DIN 43 772, ASME and special designs to customer specifications
- Connection heads form A and B acc. to EN 50 446
- Ceramic connection sockets
- Connection cables acc. to DIN 43 722 (DIN 43 714), IEC 60 584-3 and special designs

RÖSSEL-Messtechnik GmbH
Lohstraße 2
D-59368 Werne
Fon: +49 (0) 2389 409-0
Fax: +49 (0) 2389 409-80
Mail: info@roesselwerne.de
Web: www.roesselwerne.de

RÖSSEL-Messtechnik GmbH
Spenerstraße 1
D-01309 Dresden
Fon: +49 (0) 351 31225-0
Fax: +49 (0) 351 31225-25
Mail: info@roesseldresden.de
Web: www.roesseldresden.de

RÖSSEL Nederland
Eikenlaan 253d
NL-2404BP Alphen a/d Rijn
Fon: +31 (0) 172 493141
Fax: +31 (0) 172 495043
Mail: info@rossel.nl
Web: www.rossel.nl

Version 04 / 09