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Construction and application of platinum temperature sensors

Introduction

As long as 130 years ago, Sir William Siemens made the suggestion that the change of electrical resistance of metals as a result of changes in temperature could be utilized for the measurement of temperature itself. The material to be used should be a noble metal: platinum, since platinum shows characteristics that are not shared by other metals. In 1886 Siemens continued to develop the platinum resistance thermometer, and, by taking appropriate precautions, constructed a precision resistance thermometer that was suitable for measuring high temperatures.

Since then, platinum resistance thermometers have been used as indispensable devices for measuring temperature as a physical variable. These days, specially adapted designs make it possible to cover a multitude of applications over the temperature range from –200 to +850 °C. Platinum thermometers can thus be used not only in industrial measurement technology, but in sectors such as HVAC engineering, household equipment, medical and electrical engineering, as well as in automobile technology.

Wirewound platinum temperature sensors on a glass or ceramic core as well as platinum chip sensors made in thin-film technology are incorporated as the temperature-sensitive heart of the resistance thermometer.

Temperature-dependent resistance

Platinum temperature sensors use the effect of the temperature-dependence of the electrical resistance of the noble metal platinum. Since the electrical resistance increases with rising temperature, we speak of a positive temperature coefficient (often abbreviated to PTC) for such temperature sensors.

In order to use this effect for measuring temperature, the metal must vary its electrical resistance with temperature in a reproducible manner. The characteristic properties of the metal must not change during operation, as this would result in measurement errors. The temperature coefficient should, as far as possible, be independent of temperature, pressure and chemical influences.

Standardized platinum temperature sensors

For more than 130 years, platinum has been the basic material of choice for temperature-dependent sensors. It has the advantage that it is highly resistant to corrosion, is relatively easy to work (especially in wire manufacture), is available in a very pure state and exhibits good reproducibility of its electrical properties. In order to maintain the features noted above and to ensure interchangeability, these characteristics are defined in the internationally valid standard IEC 751 (translated in Germany as the DIN EN 60 751).

This standard specifies the electrical resistance as a function of temperature (table of reference values), permissible tolerances (as tolerance classes), the characteristic curves and usable temperature range.

The characteristic curves are calculated using certain coefficients, whereby the calculation distinguishes between the temperature ranges from

–200 to 0 °C and from 0 to 850 °C.

The range –200 to 0 °C is covered by a third-order polynomial:

$$R(t) = R_0 (1 + A \times t + B \times t^2 + C \times (t - 100\,°C) \times t^3)$$

A second-order polynomial is applied for the range 0 to 850 °C

$$R(t) = R_0 (1 + A \times t + B \times t^2)$$

with the coefficients

$$A = 3.9083 \times 10^{-3}\,°C^{-1}$$
$$B = -5.775 \times 10^{-7}\,°C^{-2}$$
$$C = -4.183 \times 10^{-12}\,°C^{-4}$$

The term R_0 is referred to as the nominal value, and represents the resistance at 0 °C.

According to EN 60 751, the nominal value is 100.000 Ω at 0 °C. It is therefore referred to as a Pt 100 temperature sensor.

Temperature sensors with higher nominal values are also available on the market, such as Pt 500 and Pt 1000.

They have greater sensitivity, since the slope of the characteristic is directly proportional to R_0, the nominal value. Their advantage thus lies in the fact that their resistance has a larger change with temperature.

The resistance change in the temperature range up to 100 °C is approximately:

0,4 Ω / °C for Pt 100 temperature sensors

2,0 Ω / °C for Pt 500 temperature sensors

and

4,0 Ω / °C for Pt 1000 temperature sensors.

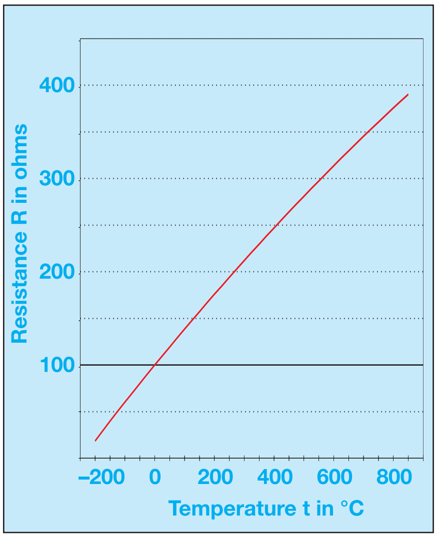

Fig. 1: Pt100 characteristic

As an additional parameter, the standard defines a mean temperature coefficient between 0 °C and 100 °C.

It represents the average change in resistance, referred to the nominal value at 0 °C:

$$\alpha = \frac{R_{100} - R_0}{R_0 \times 100\,°C} = 3.850 \times 10^{-3}\,°C^{-1}$$

R_0 and R_{100} are the resistance values for the temperatures 0 °C and 100 °C respectively.

Calculating the temperature from the resistance

For the use as a thermometer, the resistance of the temperature sensor is used to calculate the corresponding temperature. The formulae cited above define the variation in electrical resistance as a function of temperature.

For temperatures above 0 °C, a closed form of the representation of the characteristic according to EN 60 751 can be derived to determine the temperature.

$$t = \frac{-R_0 \times A + [(R_0 \times A)^2 - 4 \times R_0 \times B \times (R_0 - R)]^{1/2}}{2 \times R_0 \times B}$$

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R = resistance, measured in Ω

t = temperature, calculated in °C

R_0, A, B = parameters as per EN 60 751

Tolerance limits

The standard distinguishes between two tolerance classes:

Class A: $\Delta t = \pm\,(0.15 + 0.002 \times |t|)$
Class B: $\Delta t = \pm\,(0.30 + 0.005 \times |t|)$

t = temperature, in °C (without math. sign)

The calculation of the tolerance limit ΔR in Ω at a temperature of t > 0 °C is given by:

$$\Delta R = R_0\,(A + 2 \times B \times t) \times \Delta t$$

For t < 0 °C it is:

$$\Delta R = R_0\,(A + 2 \times B \times t - 300\,°C \times t^2 + 4 \times C \times t^3) \times \Delta t$$

Tolerance Class A applies for temperatures from –200 to +600 °C.

Tolerance Class B applies for the entire defined range from –200 to +850 °C.

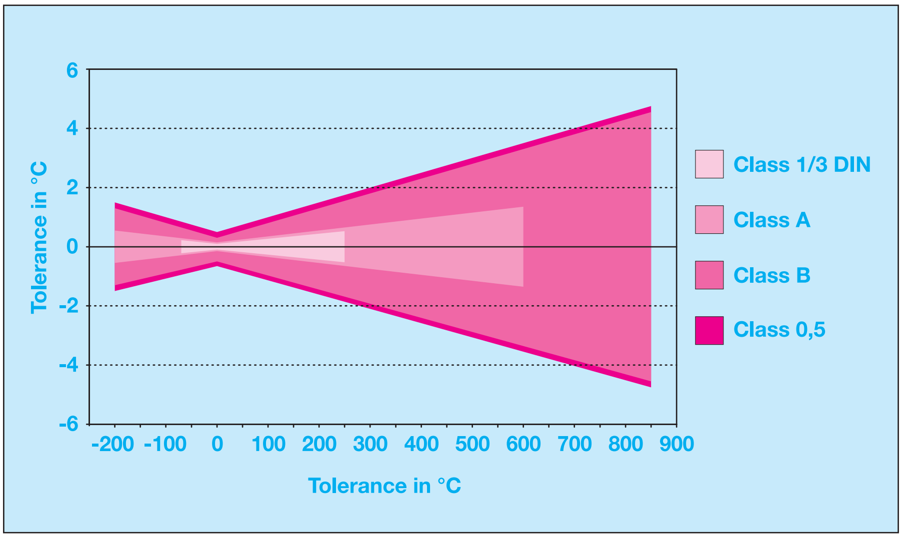

Fig. 2: Tolerance band as a function of the temperature

Extended tolerance classes

The two tolerance classes specified in the standard are frequently inadequate for certain applications. JUMO has defined a further division of the tolerance classes, based on the standardized tolerances, in order to cover the widest possible range of applications throughout the market.

In addition to the definition equations for the temperature-dependent deviations, the range of validity has also been defined. Because of the inexactly linear relationship between the resistance and temperature, measurements must be made at various temperatures to determine the deviations from the standard curve 3 (for t > 0 °C) or 4 (for t < 0 °C) respectively. For series manufacture of temperature sensors, tests are generally made only at 0 °C and 100 °C. So it is not possible to make a precise determination of the individual characteristic of a temperature sensor. Since, on the one hand, it is not possible to make the measurement uncertainty endlessly small and, on the other hand, the characteristic curve is subject to variations caused by production tolerances, the range of validity of the narrower tolerance classes must be restricted compared with the measuring range of the temperature sensor.

Another conclusion from this situation is that the temperature classes cannot be narrowed without limit.

Temperature	Class 1/3 DIN B	Class A	Class B	Class 0.5
–200 °C		0.55 °C	1.30 °C	1.70 °C
–70 °C	0.22 °C	0.29 °C	0.65 °C	0.92 °C
0 °C	0.10 °C	0.15 °C	0.30 °C	0.50 °C
100 °C	0.27 °C	0.35 °C	0.80 °C	1.10 °C
250 °C	0.53 °C	0.65 °C	1.55 °C	2.00 °C
350 °C		0.85 °C	2.05 °C	2.60 °C
600 °C		1.35 °C	3.30 °C	4.10 °C
850 °C			4.55 °C	5.60 °C

Table 2: ± Tolerance in °C according to class

Practical situation

Temperature sensors with tightened tolerances usually have a considerably wider measuring range. This has the practical result that temperature sensors which are used at the upper or lower temperature limits can only achieve the given tolerance within the range of validity. Outside the range of validity, it is possible that the tolerance will be exceeded and then the standard Class B tolerance must be applied.

Measurement point

Before delivery, all temperature sensors are completely checked and measured,

Tolerance class	Sensor category	Temperature range	Tolerance in °C
Class 1/3 DIN B	Thin-film Wire	–50 to +200 °C –70 to +250 °C	$\pm\,(0.10\,K + 0.0017 \times |t|)$
Class A	Thin-film Wire	–70 to +300 °C –200 to +600 °C	$\pm\,(0.15\,K + 0.002 \times |t|)$
Class B	Thin-film Wire	–70 to +600 °C –200 to +850 °C	$\pm\,(0.30\,K + 0.005 \times |t|)$
Class 0.5	Thin-film Wire	–70 to +600 °C –200 to +850 °C	$\pm\,(0.50\,K + 0.006 \times |t|)$

Table 1: Tolerance classes – Temperature validity range *|t| = measured temperature in °C (without sign)*

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and selected into tolerance classes. The measurement uncertainty of the classification equipment is taken into account. During the measurement, both the temperature sensors and the connecting wires are at the specific temperature for the measurement. Four-wire connections are made 2 mm from the open ends of the connecting wires. During further processing of the temperature sensors it must be noted that any alteration of the length of the connecting wires will alter the resistance for 2-wire measurement. In exceptional cases this may cause the tolerance limits to be exceeded, positively or negatively.

Self-heating

In order to obtain an output signal from a temperature sensor, a current must flow through the sensor. This measuring current generates heat losses which warm up the temperature sensor. The result is an higher indicated temperature. Self-heating depends on various factors, one of which is the extent to which the self-generated heat can be removed by the medium being measured.

The formula for electrical power $P = R \times I^2$ means that this effect also depends on the nominal resistance value (R) of the temperature sensor: For a given measuring current, a Pt 1000 temperature sensor will generate 10 times as much heat as a Pt 100. So the advantage of higher sensitivity brings the disadvantage of increased self-heating. If a temperature rise of 0.1 °C is permitted in running water, then the current level for wirewound ceramic temperature sensors will be between 3 and 50 mA, depending on the size, and for thin-film temperature sensors it will be about 1 mA.

In still air the permissible current level will have to be reduced by a factor of about 50. If the temperature sensor is mounted in a protective fitting, then the self-heating characteristics will be altered. The permissible current levels lie between the two extremes noted above, and depend on the thermal boundaries, size, heat conduction, and heat capacity of the protective fitting.

Thermometer manufacturers often state a self-heating coefficient in the corresponding documentation. This coefficient provides a value for the temperature increase caused by a defined power loss produced in the temperature sensor. Such calorimetric measurements are carried out under defined conditions (in water flowing at 0.2 meters / sec or air at 2 meters / sec) but the results have a somewhat theoretical nature and are used as figures of merit when comparing different types of construction. In most cases, the manufacturer defines the measuring current as 1 mA, since this value has proven to be an acceptable practical value that does not generate a significant amount of self-heating.

For instance, if a 1 mA measuring current is passed through a Pt 100 sensor mounted in a (thermally) completely insulated container with an air volume of 10 cm³, then the air will be warmed up by about 39 °C after one hour.

Any flow of gas or liquid will reduce this effect, because of the considerably increased removal of the heat that is generated.

The self-heating must be measured at the point of installation, depending on the circumstance of the measuring setup. The temperature must be measured at various different current levels. The self-heating coefficient E can then be derived as follows:

$$E = \Delta t / (R \times I^2)$$

Where Δt = (indicated temperature) – (temperature of the medium), R = resistance of the temperature sensor, I = measuring current

The self-heating coefficient can then be used to define the maximum permissible measuring current for a given permissible measurement error Δt.

$$I = (\Delta t / E \times R)^{1/2}$$

Long-term behavior

In addition to the tolerance of the temperature sensor, the long-term behavior is an important parameter, since it is the major factor determining the maintenance of the measurement uncertainty during the operating life of the device under its defined conditions. The values given in the data sheets are guidance values, determined through measurements on the specific type of sensor, not made-up in any way, in an oven with a normal atmosphere. The further processing of the temperature sensors and the characteristics of the materials with which it comes into contact may affect the long-term stability. It is therefore to be recommended that the long-term stability of a particular design should be established under the intended operating conditions, so that external influences may also be taken into account.

Response

If the temperature sensor is subjected to a sudden change in temperature, then there will be a distinct time lag before it has taken up the new temperature. This time is dependent on the style of the temperature sensor and the ambient conditions, such as the medium being measured and the flow rate of the same. The figures given in the data sheets refer to measurements in agitated water, at a flow of v = 0.4 meters / sec or in air at a flow of 1 meter / sec.

The response times for other media can be calculated with the aid of the heat transfer coefficient as per VDI / VDE 3522. Fig. 3 shows a typical response curve (transfer function).

The specific times derived are those taken by the sensor to reach 50 % or 90 % of the final (steady) value.

The transfer function, i.e. the way in which the measured value changes after a step change in temperature at the sensor, provides this information.

The transfer function is measured by passing a current of warm water or air across the temperature sensor.

Two times (settling times) characterize the transfer function:

- **Half-value time $t_{0.5}$**
  This is the time taken for the measurement to reach 50 % of the final value, and the
- **90 % time $t_{0.9}$**
  in which 90 % of the final value is reached.

A time t, the time taken to reach 63.2 % of the final value, is not given, because it is

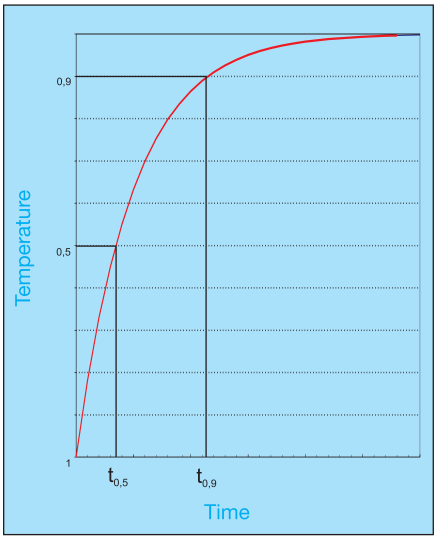

Fig. 3: Transfer function

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easily mistaken for the time constant of an exponential function. The heat transfer function of practically all temperature sensors shows significant deviations from such a function.

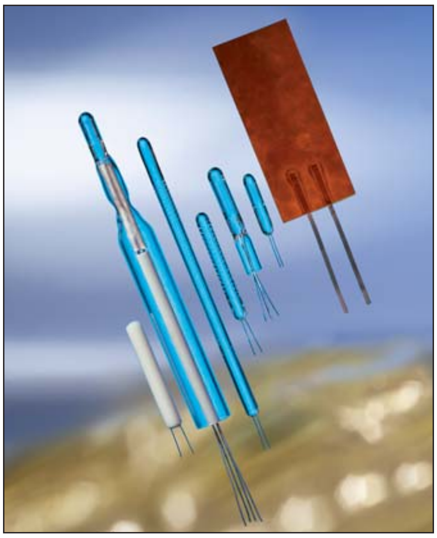

Fig. 4: Product selection

Styles

Principally, platinum temperature sensors can be divided into two fundamentally different categories. We can distinguish between temperature sensors with a solid wire winding in glass, ceramic or foil versions, and temperature sensors manufactured using the latest thin-film technology. The classic platinum temperature sensor is based on the wirewound

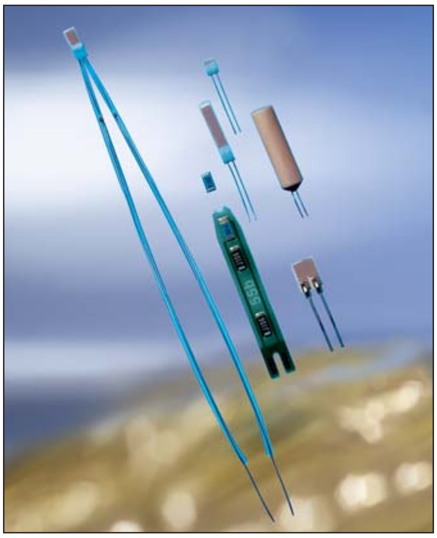

Fig. 5: Product selection

Fig. 6: Producing temperature sensors under clean-room conditions

construction.

In spite of partially automated production processes, a common feature of all such styles is a high level of manual labor in production.

Wirewound temperature sensors

Platinum-glass temperature sensors (PG style)

Platinum-glass temperature sensors belong to the category of wirewound constructions. One or two measurement windings are wound on a glass rod, each in the form of a bifilar winding. The winding is fused onto the glass and provided with connecting wires. The nominal resistance value is calibrated by altering the length of the winding. Afterwards, a sleeve is pushed over the glass rod + measurement winding, and the components are then fused together.

The glass that is used is matched to the expansion coefficient of the platinum wire. An additional artificial ageing process ensures that good long-term stability is achieved. The operating temperature covers the range from –200 to +400 °C.

JUMO platinum-glass temperature sensors are distinguished by a design that is extremely resistant to shock and vibration. Furthermore, the connecting wires exhibit a very high tensile strength. Another advantage of this style is that the temperature sensors can readily be used for measurement in highly humid environments or directly in the liquid, thanks to the hermetic sealing of the measurement winding and the excellent chemical resistance of the glass. In addition, the familiar protection tube – a necessary component with other styles – can now be dispensed with, allowing short response times.

A wide variety of platinum-glass temperature sensors is available in many different geometries. As well as the versions with a standard nominal resistance of 100 Ω at 0 °C, JUMO also supplies platinum-glass temperature sensors with 500 Ω and 1000 Ω nominal values, as well as special values on request. Versions with a glass extension or double measurement windings are also possible.

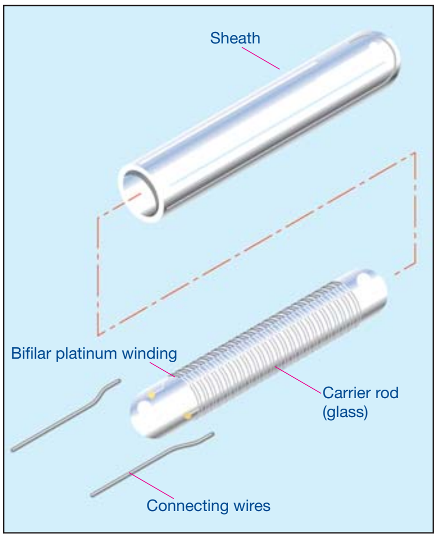

Fig. 7: Basic construction of platinum-glass temperature sensors (PG style)

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Platinum-glass laboratory resistance thermometers

Electrical glass thermometers for laboratory applications frequently have to meet especially high demands.

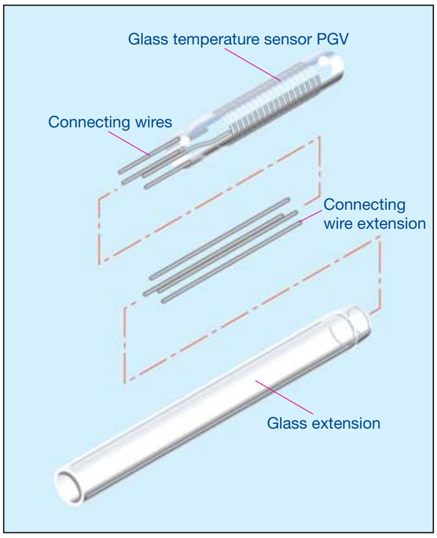

Fig. 8: Basic construction of platinum-glass temperature sensors with glass extension (style for laboratory resistance thermometers)

Laboratory resistance thermometers are made by a supplementary processing of platinum-glass temperature sensors. Temperature sensors in the PGL style, for instance, can be fitted with glass tube extensions in various lengths. Depending on the specific measurement task, such glass extensions can also be supplied with a standard ground joint, diameter graduations, or even as angled versions.

The electrical connection of the resistance thermometer is made via a connector system (e.g. LEMOSA), or directly through an attached cable. Connections can be made in 2-wire, 3-wire or 4-wire circuit, according to choice. Laboratory resistance thermometers can optionally be supplied in a variety of tolerance classes, such as the tighter tolerance of Class A as per EN 60 751. JUMO laboratory resistance thermometers can also be delivered with a DKD calibration certificate.

As a specialist for manufacturing a wide product spectrum, JUMO offers solutions for many customer-specific requirements.

Platinum-ceramic temperature sensors (PK style)

Platinum-ceramic temperature sensors use a ceramic tube as the carrier material, in which there are either two or four bores, depending on the version to be produced. A platinum coil that has already been calibrated and fitted with connection wires is inserted into each of the bores. Platinum-glass temperature sensors therefore also belong to the category of wirewound constructions. The remaining space in the bores is then filled with alumina powder, to fix the coils and to improve heat transfer. Both ends of the ceramic body are then closed with a sealing compound that is fused on. This seals off the embedded measurement windings and also stabilizes the connecting wires. Platinum-ceramic temperature sensors are available with diameters as small as 0.9 mm. Their overall length varies, in general, from 4 to 30 mm. As far as the nominal value is concerned, this style is normally only available with Pt 100 temperature sensors.

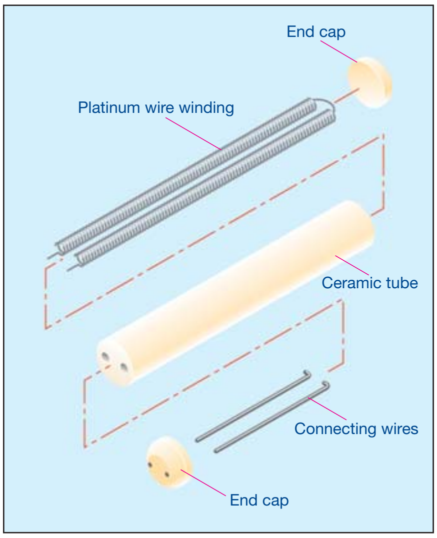

Fig. 10: Basic construction of platinum-ceramic temperature sensors (PK style)

Platinum-ceramic temperature sensors are mainly used for high-temperature measurement. They have the highest overall usable temperature range, stretching from –200 to +800 °C.

The special internal construction of the platinum-ceramic temperature sensors largely prevents permanent changes in the resistance value, which may occur in other styles as a result of substantial temperature cycling or shock-like temperature changes.

However, the application of this style must be restricted if strong vibration or shocks are to be expected in the application.

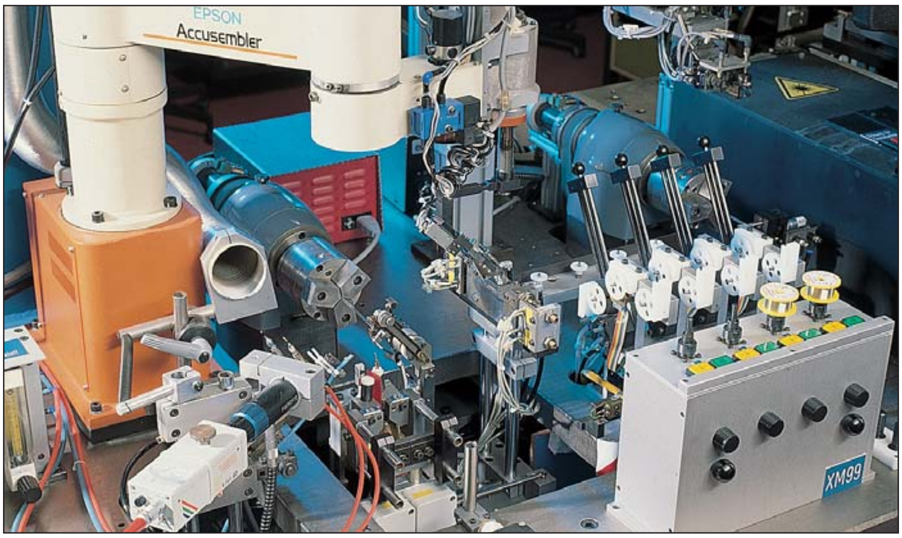

Fig. 9: Automated production of wirewound platinum-glass temperature sensors

Platinum-foil temperature sensors (PF style)

Like glass or ceramic temperature sensors, platinum-foil temperature sensors also belong to the category of wirewound styles. A winding of solid platinum wire is embedded between two self-adhesive polyimide foils. The platinum winding is calibrated through the adjustment of the winding length, before the foils are joined. The electrical characteristics conform to EN 60 751. Two nickel tapes are taken out to form the electrical connection.

JUMO platinum-foil temperature sensors are especially suitable for measurements on flat

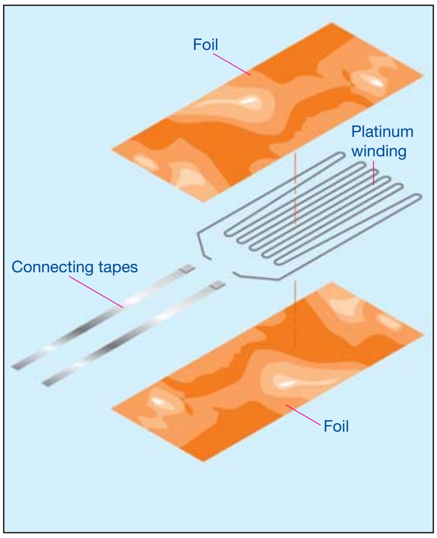

Fig. 11: Basic construction of platinum-foil temperature sensors (PF style)

or even slightly curved surfaces. Furthermore, their flexibility and small thickness enable measurements at sites that are difficult to access. Thanks to their low intrinsic mass and relatively large surface area, these foil temperature sensors achieve fast response. Foil temperature sensors are designed for applications at temperatures from –80 to +180 °C.

Thin-film temperature sensors

Since the early 80s, JUMO has taken production processes from semiconductor technology and used them to manufacture platinum-chip temperature sensors. This was linked to the start of a continual process of miniaturization that is not yet at an end, even today, and is following two routes: a reduction of component sizes and an increase in nominal values, and, parallel to this technological development, a continual reduction of production costs, so that the technical advantages of platinum-chip temperature sensors can also be used in mass production applications.

Platinum-chip temperature sensors with connecting wires (PCA style)

Platinum-chip temperature sensors are manufactured in the latest thin-film techniques, in clean-room conditions. Unlike the wirewound versions, the platinum layer in thin-film temperature sensors is applied to a ceramic substrate through a sputtering process. This platinum coating is then formed into a serpentine structure by a photolithographic process, and then adjusted by a laser-trimming method.

The electrical connection is made through special contact areas, onto which the connecting wires are bonded. A fused layer of glass protects the platinum serpentine from external influences and also serves as insulation.

The contact areas of the connecting wires on the sensor are fixed by another glass layer, which also provides strain relief.

The temperature at which platinum-chip temperature sensors can be used depends on the version, and is usually in the range from –70 to +600 °C. Platinum-chip temperature sensors can also be used to some extent at much lower temperatures, if they are previously given a special artificial ageing treatment.

Fig. 12: Laser trimming of platinum-chip temperature sensors

Thin-film temperature sensors combine the favorable properties of a platinum sensor, such as interchangeability, long-term stability, reproducibility and wide temperature measurement range, with the advantages of large-scale production. And, thanks to the small dimensions and low mass, very fast response times are achieved. In addition, they can also achieve high nominal values in very small dimensions, compared with glass and ceramic temperature sensors.

Platinum-chip temperature sensors with terminal clamps (PCKL style)

PCKL style platinum-chip temperature sensors are manufactured in the same way as the standard PCA styles. However, there are some differences in the connecting wire techniques that are used.

Compared with the standard PCA style temperature sensors, these sensors do not feature bonded connecting wires, but have terminal clamps that are soldered on.

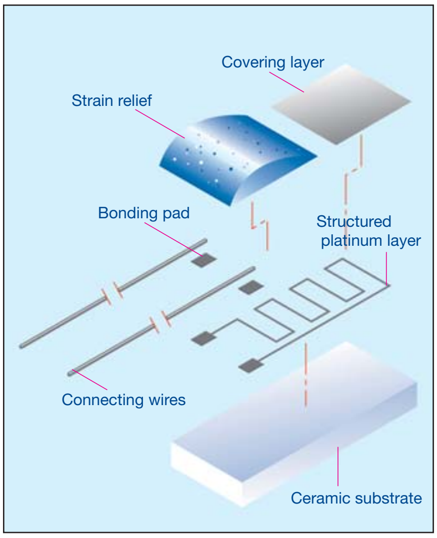

Fig. 13: Basic construction of platinum-chip temperature sensors with connecting wires (PCA style)

These terminal clamps are especially rigid and exhibit a high bending strength. This characteristic gives the temperature sensors an outstanding directional stability.

PCKL style platinum-chip temperature sensors are thus preferred for various

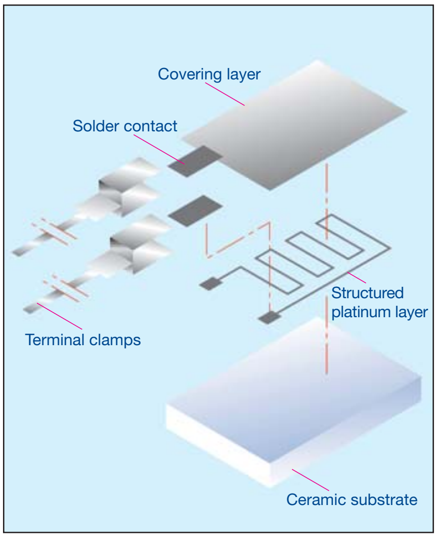

Fig. 14: Basic construction of platinum-chip temperature sensors with terminal clamps (PCKL style)

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types of probe construction in climatic measurement technology. The entire temperature sensor, including the solder joint and terminal clamps (with bare wire ends), is additionally coated with a protective varnish, to protect against condensation and external effects.

The operating temperature range is –40 to +105 °C.

Platinum-chip temperature sensors in cylindrical style (PCR style)

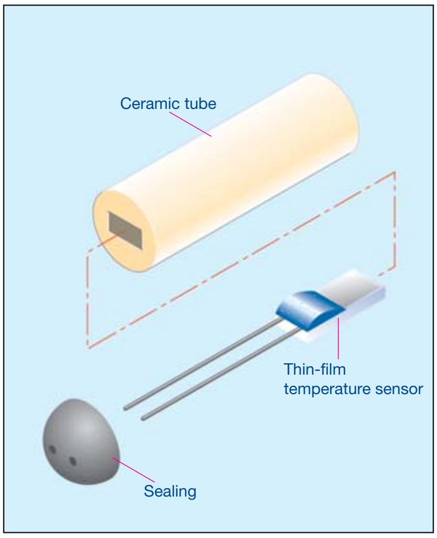

Fig. 15: Basic construction of platinum-chip temperature sensors in cylindrical form (PCR style)

Basically, this style incorporates a platinum-chip temperature sensor which is inserted into a ceramic sleeve that is open at one end. After inserting the platinum-chip temperature sensor, the opening of the ceramic sleeve is hermetically sealed with a sealing compound. The round body of this type of platinum-chip temperature sensor enables a good adaptation to the inner walls of protection tubes, and also protects the sensor from external influences. In addition, this style exhibits high mechanical rigidity, thus facilitating an embedding in many types of bulk adhesive. It is frequently used in the construction of equipment and machinery.

JUMO temperature sensors in cylindrical style present a cost-effective alternative to wirewound ceramic temperature sensors. Platinum-chip temperature sensors in this cylindrical style are designed for operating temperatures from –70 to +300 °C.

Platinum-chip temperature sensors in SMD style (PCS style)

Platinum-chip temperature sensors in SMD style belong to the category of thin-film temperature sensors. Like the similarly designed PCA styles, they are manufactured in the latest thin-film techniques, in clean-room conditions. During production of these temperature sensors, a platinum layer, which constitutes the active layer, is formed into a serpentine structure and applied to a ceramic substrate.

The platinum serpentine is provided with two solder contacts at the opposing lengthwise ends of the temperature sensor, to make the electrical connection. The glass layer that is applied after the adjustment protects the platinum serpentine against external effects.

Unlike wire-ended styles, SMD temperature sensors are specially designed for automatic placing on electronic circuit boards in large-scale production.

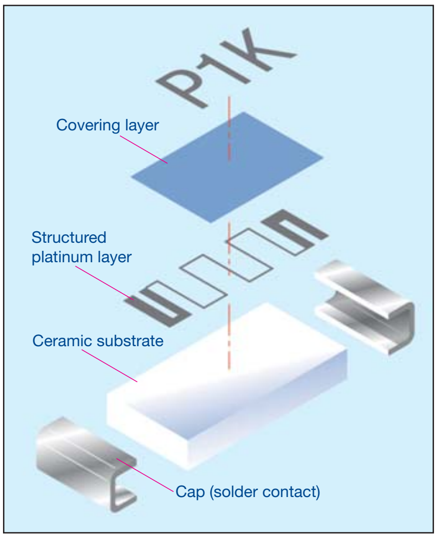

Fig. 16: Basic construction of platinum-chip temperature sensors in SMD form (PCS style)

Platinum-chip temperature sensors on epoxy card (PCSE style)

PCSE style platinum-chip temperature sensors constitute a pre-assembled version. The epoxy card carries an assembled SMD temperature sensor as the active component to acquire the temperature. The resistance signal is transmitted to the contact surfaces on opposing sides, via thin tracks. At these points, a variety of connecting wires can be attached for a range of wire-ended probe versions. The use of this style (with a base card) has the advantage that any possible tension on the connecting cable cannot be transmitted directly to the temperature sensor. Furthermore, the thin conductor tracks achieve a considerable reduction of any measurement error caused by heat conduction.

This style was designed especially as a measuring insert, making it considerably easier to fabricate different versions of wire-ended probes. This also enables automated production steps, thus achieving the lowest possible cost levels.

PCSE style platinum-chip temperature sensors are suitable for operation over a temperature range from –20 to +150 °C.

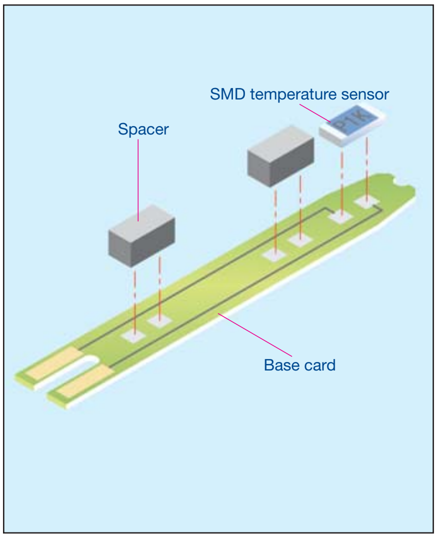

Fig. 17: Basic construction of platinum-chip temperature sensors on epoxy card (PCSE style)

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Reference values to EN 60 751 (ITS 90)

in Ohm for Pt100 temperature sensors in 1°C steps

°C	-0	-1	-2	-3	-4	-5	-6	-7	-8	-9
-200	18.520	-	-	-	-	-	-	-	-	-
-190	22.825	22.397	21.967	21.538	21.108	20.677	20.247	19.815	19.384	18.952
-180	27.096	26.671	26.245	25.819	25.392	24.965	24.538	24.110	23.682	23.254
-170	31.335	30.913	30.490	30.067	29.643	29.220	28.796	28.371	27.947	27.552
-160	35.543	35.124	34.704	34.284	33.864	33.443	33.022	32.601	32.179	31.757
-150	39.723	39.306	38.889	38.472	38.055	37.637	37.219	36.800	36.382	35.963
-140	43.876	43.462	43.048	42.633	42.218	41.803	41.388	40.972	40.556	40.140
-130	48.005	47.593	47.181	46.769	46.356	45.944	45.531	45.117	44.704	44.290
-120	52.110	51.700	51.291	50.881	50.470	50.060	49.649	49.239	48.828	48.416
-110	56.193	55.786	55.378	54.970	54.562	54.154	53.746	53.337	52.928	52.519
-100	60.256	59.850	59.445	59.039	58.633	58.227	57.821	57.414	57.007	56.600
- 90	64.300	63.896	63.492	63.088	62.684	62.280	61.876	61.471	61.066	60.661
- 80	68.325	67.924	67.552	67.120	66.717	66.315	65.912	65.509	65.106	64.703
- 70	72.335	71.934	71.534	71.134	70.733	70.332	69.931	69.530	69.129	68.727
- 60	76.328	75.929	75.530	75.131	74.732	74.333	73.934	73.534	73.134	72.735
- 50	80.306	79.909	79.512	79.114	78.717	78.319	77.921	77.523	77.125	76.726
- 40	84.271	83.875	83.479	82.083	82.687	82.290	81.894	81.497	81.100	80.703
- 30	88.222	87.827	87.432	87.038	86.643	86.248	85.853	85.457	85.062	84.666
- 20	92.160	91.767	91.373	90.980	90.586	90.192	89.798	89.404	89.010	88.616
- 10	96.086	95.694	95.302	94.909	94.517	94.124	93.732	93.339	92.946	92.553
0	100.000	99.609	99.218	98.827	98.436	98.044	97.653	97.261	96.870	96.478

°C	0	1	2	3	4	5	6	7	8	9
0	100.000	100.391	100.781	101.172	101.562	101.953	102.343	102.733	103.123	103.513
10	103.903	104.292	104.682	105.071	105.460	105.849	106.238	106.627	107.016	107.405
20	107.794	108.182	108.570	108.959	109.347	109.735	110.123	110.510	110.898	111.286
30	111.673	112.060	112.447	112.835	113.221	113.608	113.995	114.382	114.768	115.155
40	115.541	115.927	116.313	116.699	117.085	117.470	117.856	118.241	118.627	119.012
50	119.397	119.782	120.167	120.552	120.936	121.321	121.705	122.090	122.474	122.858
60	123.242	123.626	124.009	124.393	124.777	125.160	125.543	125.926	126.309	126.692
70	127.075	127.458	127.840	128.223	128.605	128.987	129.370	129.752	130.133	130.515
80	130.897	131.278	131.660	132.041	132.422	132.803	133.184	133.565	133.946	134.326
90	134.707	135.087	135.468	135.848	136.228	136.608	136.987	137.367	137.747	138.126
100	138.506	138.885	139.264	139.643	140.022	140.400	140.779	141.158	141.536	141.914
110	142.293	142.671	143.049	143.426	143.804	144.182	144.559	144.937	145.314	145.691
120	146.068	146.445	146.822	147.198	147.575	147.951	148.328	148.704	149.080	149.456
130	149.832	150.208	150.583	150.959	151.334	151.710	152.085	152.460	152.865	153.210
140	153.584	153.959	154.333	154.708	155.082	155.456	155.830	156.204	156.578	156.952
150	157.325	157.699	158.072	158.445	158.818	159.191	159.564	159.937	160.309	160.682
160	161.054	161.427	161.799	162.171	162.543	162.915	163.286	163.658	164.030	164.401
170	164.772	165.143	165.514	165.885	166.256	166.627	166.997	167.368	167.738	168.108
180	168.478	168.848	169.218	169.588	169.958	170.327	170.696	171.066	171.435	171.804
190	172.173	172.542	172.910	173.279	173.648	174.016	174.384	174.752	175.120	175.488
200	175.856	176.224	176.591	176.959	177.326	177.693	178.060	178.427	178.794	179.161
210	179.528	179.894	180.260	180.627	180.993	181.359	181.725	182.091	182.456	182.822
220	183.188	183.553	183.918	184.283	184.648	185.013	185.378	185.743	186.107	186.472
230	186.836	187.200	187.564	187.928	188.292	188.656	189.019	189.383	189.746	190.110
240	190.473	190.836	191.199	191.562	191.924	192.287	192.649	193.012	193.374	193.736
250	194.098	194.460	194.822	195.183	195.545	195.906	196.268	196.629	196.990	197.351
260	197.712	198.073	198.433	198.794	199.154	199.514	199.875	200.235	200.595	200.954
270	201.314	201.674	202.033	202.393	202.752	203.111	203.470	203.829	204.188	204.546
280	204.905	205.263	205.622	205.980	206.338	206.696	207.054	207.411	207.769	208.127
290	208.484	208.841	209.198	209.555	209.912	210.269	210.626	210.982	211.339	211.695
300	212.052	212.408	212.764	213.120	213.475	213.831	214.187	214.542	214.897	215.252

The reference values have been calculated according to the International Temperature Scale ITS 90.
(For Pt500 or Pt1000 temperature sensors, the reference values have to be multiplied by 5 or 10 respectively).

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Reference values to EN 60 751 (ITS 90)

in Ohm for Pt100 temperature sensors in 1°C steps

°C	0	1	2	3	4	5	6	7	8	9
310	215.608	215.962	216.317	216.672	217.027	217.381	217.736	218.090	218.444	218.798
320	219.152	219.506	219.860	220.213	220.567	220.920	221.273	221.626	221.979	222.332
330	222.685	223.038	223.390	223.743	224.095	224.447	224.799	225.151	225.503	225.855
340	226.206	226.558	226.909	227.260	227.612	227.963	228.314	228.664	229.015	229.366
350	229.716	230.066	230.417	230.767	231.117	231.467	231.816	232.166	232.516	232.865
360	233.214	233.564	233.913	234.262	234.610	234.959	235.308	235.656	236.005	236.353
370	236.701	237.049	237.397	237.745	238.093	238.440	238.788	239.135	239.482	239.829
380	240.176	240.523	240.870	241.217	241.563	241.910	242.256	242.602	242.948	243.294
390	243.640	243.986	244.331	244.677	245.022	245.367	245.713	246.058	246.403	246.747
400	247.092	247.437	247.781	248.125	248.470	248.814	249.158	249.502	249.845	250.189
410	250.533	250.876	251.219	251.562	251.906	252.248	252.591	252.934	253.277	253.619
420	253.962	254.304	254.646	254.988	255.330	255.672	256.013	256.355	256.696	257.038
430	257.379	257.720	258.061	258.402	258.743	259.083	259.424	259.764	260.105	260.445
440	260.785	261.125	261.465	261.804	262.144	262.483	262.823	263.162	263.501	263.840
450	264.179	264.518	264.857	265.195	265.534	265.872	266.210	266.548	266.886	267.224
460	267.562	267.900	268.237	268.574	268.912	269.249	269.586	269.923	270.260	270.597
470	270.933	271.270	271.606	271.942	272.278	272.614	272.950	273.286	273.622	273.957
480	274.293	274.628	274.963	275.298	275.633	275.968	276.303	276.638	276.972	277.307
490	277.641	277.975	278.309	278.643	278.977	279.311	279.644	279.978	280.311	280.644
500	280.978	281.311	281.643	281.976	282.309	282.641	282.974	283.306	283.638	283.971
510	284.303	284.634	284.966	285.298	285.629	285.961	286.292	286.623	286.954	287.285
520	287.616	287.947	288.277	288.608	288.938	289.268	289.599	289.929	290.258	290.588
530	290.918	291.247	291.577	291.906	292.235	292.565	292.894	293.222	293.551	293.880
540	294.208	294.537	294.865	295.193	295.521	295.849	296.177	296.505	296.832	297.160
550	297.487	297.814	298.142	298.469	298.795	299.122	299.449	299.775	300.102	300.428
560	300.754	301.080	301.406	301.732	302.058	302.384	302.709	303.035	303.360	303.685
570	304.010	304.335	304.660	304.985	305.309	305.634	305.958	306.282	306.606	306.930
580	307.254	307.578	307.902	308.225	308.549	308.872	309.195	309.518	309.841	310.164
590	310.487	310.810	311.132	311.454	311.777	312.099	312.421	312.743	313.065	313.386
600	313.708	314.029	314.351	314.672	314.993	315.314	315.635	315.956	316.277	316.597
610	316.918	317.238	317.558	317.878	318.198	318.518	318.838	319.157	319.477	319.796
620	320.116	320.435	320.754	321.073	321.391	321.710	322.029	322.347	322.666	322.984
630	323.302	323.620	323.938	324.256	324.573	324.891	325.208	325.526	325.843	326.160
640	326.477	326.794	327.110	327.427	327.744	328.060	328.376	328.692	329.008	329.324
650	329.640	329.956	330.271	330.587	330.902	331.217	331.533	331.848	332.162	332.477
660	332.792	333.106	333.421	333.735	334.049	334.363	334.677	334.991	335.305	335.619
670	335.932	336.246	336.559	336.872	337.185	337.498	337.811	338.123	338.436	338.748
680	339.061	339.373	339.685	339.997	340.309	340.621	340.932	341.244	341.555	341.867
690	342.178	342.489	342.800	343.111	343.422	343.732	344.043	344.353	344.663	344.973
700	345.284	345.593	345.903	346.213	346.522	346.832	347.141	347.451	347.760	348.069
710	348.378	348.686	348.995	349.303	349.612	349.920	350.228	350.536	350.844	351.152
720	351.460	351.768	352.075	352.382	352.690	352.997	353.304	353.611	353.918	354.224
730	354.531	354.837	355.144	355.450	355.756	256.062	356.368	356.674	356.979	357.285
740	357.590	357.896	358.201	358.506	358.811	359.116	359.420	359.725	360.029	360.334
750	360.638	360.942	361.246	361.550	361.854	362.158	362.461	362.765	363.068	363.371
760	363.674	363.977	364.280	364.583	364.886	365.188	365.491	365.793	366.095	366.397
770	366.699	367.001	367.303	367.604	367.906	368.207	368.508	368.810	369.111	369.412
780	369.712	370.013	370.314	370.614	370.914	371.215	371.515	371.815	372.115	372.414
790	372.714	373.013	373.313	373.612	373.911	374.210	374.509	374.808	375.107	375.406
800	375.704	376.002	376.301	376.599	376.897	377.195	377.493	377.790	378.088	378.385
810	378.683	378.980	379.277	379.574	379.871	380.167	380.464	380.761	381.057	381.353
820	381.650	381.946	382.242	382.537	382.833	383.129	383.424	383.720	384.015	384.310
830	384.605	384.900	385.195	385.489	385.784	386.078	386.373	386.667	386.961	387.255
840	387.549	387.843	388.136	388.430	388.723	389.016	389.310	389.603	389.896	390.188
850	390.481	-	-	-	-	-	-	-	-	-

The reference values have been calculated according to the International Temperature Scale ITS 90.
(For Pt500 or Pt1000 temperature sensors, the reference values have to be multiplied by 5 or 10 respectively).

Electrical Temperature Measurement

with thermocouples and resistance thermometers
by Matthias Nau

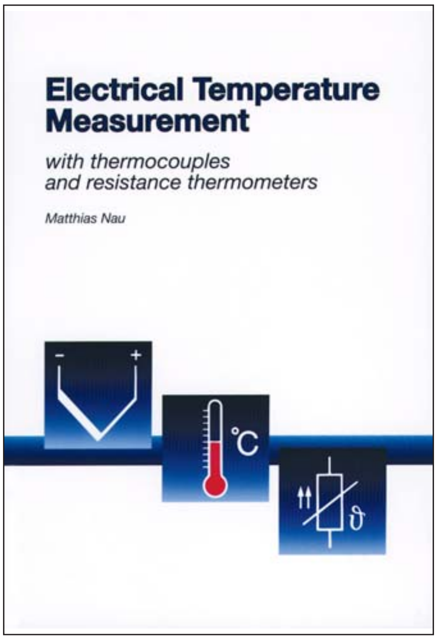

Fig. 18: Publication "Electrical temperature measurement with thermocouples and resistance thermometers"

Electrical temperature sensors have become indispensable components in modern automation, consumer goods and production technology. Particularly as a result of the rapid expansion of automation in recent years, they have become firmly established in industrial engineering.

In view of the large spectrum of products available for the electrical measurement of temperature, it is becoming ever more important for the user to select the one suitable for his application.

On 160 pages this publication deals with the theoretical fundamentals of electrical temperature measurement, the practical construction of temperature sensors, their standardization, electrical connection, tolerances and types of construction.

In addition, it describes in detail the different fittings for electrical thermometers, their classification according to DIN standards, and the great variety of applications. An extensive section of tables for standard values of voltage and resistance according to DIN and EN makes this book a valuable guide, both for the experienced practical engineer and for the novice in the field of electrical temperature measurement.

To be ordered under Sales No. 90/00085081 or as a download from www.jumo.net

Schools, institutes and universities are asked to make joint orders, because of the high handling costs.

Error Analysis of a Temperature Measurement System with worked examples
by Gerd Scheller

The 44-page publication helps in the evaluation of measurement uncertainty, particularly through the worked examples in Chapter 3. Where problems arise, we are happy to discuss specific problems with our customers, and to provide practical advice.

In order to make comparable measurements, their quality must be established through details of the measurement uncertainty. The ISO/BIPM "Guide to the Expression of Uncertainty in Measurement", published in 1993 and usually referred to as GUM, introduced a standardized method for the determination and definition of measurement uncertainty. This method was adopted by calibration laboratories around the world. However, the application requires a certain level of mathematical understanding. Further chapters present the topic of measurement uncertainty in a simplified and easily understandable fashion for all users of temperature measurement systems.

Errors in the installation of the temperature sensors and the connections to the evaluation electronics lead to increased errors in measurement. To these must be added the measurement uncertainty components of the sensor and the evaluation electronics itself. The explanation of the various components of measurement uncertainty is followed by some worked examples.

Knowledge of the various measurement uncertainty components and their magnitudes enables the user to reduce individual components through the selection of equipment or altered installation conditions. The decisive factor is always, which level of measurement uncertainty is acceptable for a specific measurement task. For instance, if a standard specifies tolerance limits for the deviation of a temperature from a given value, then the measurement uncertainty of the method used for temperature measurement should not exceed 1/3 of the tolerance.

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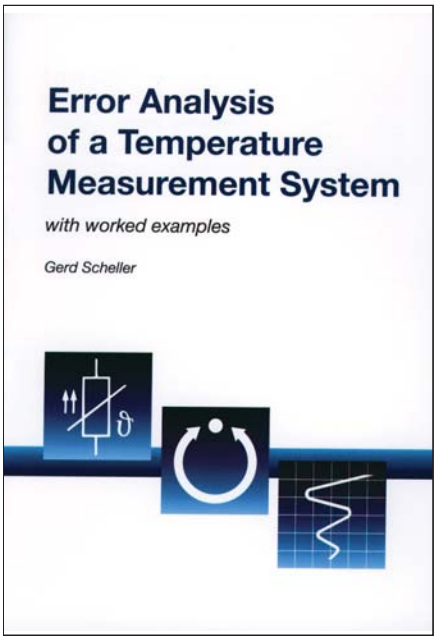

Fig. 19: Publication "Error Analysis of a Temperature Measurement System with worked examples"

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German Calibration Service (DKD) at JUMO

Certification laboratory for temperature

Raised quality expectations, improved measurement technology and, of course, quality assurance systems such as ISO 9000, make increasing demands on the documentation of processes and the monitoring of measuring equipment. To this must be added customers' demands for products with a high standard of quality. Particularly stringent demands arise from the ISO 9000 and EN 45 000 standards, whereby measurements must be traceable to national or international reference standards. This provides the legal basis for obliging suppliers and manufacturers (of products that are subject to processes where temperature is relevant) to check all test and measurement equipment that can affect the product quality, before use or at prescribed intervals. Generally, this is done by calibration or adjustment using certified equipment. Because of the high demand for calibrated instruments and the large number of instruments to be calibrated, the state laboratories have insufficient capacity. The industry has therefore established and supports special calibration laboratories which are linked to the German Calibration Service (DKD) and, in matters of measurement technology, subordinate to the Physikalisch-Technische-Bundesanstalt (PTB).

The certification laboratory of the German Calibration Service at JUMO has carried out calibration certification for temperature since 1992. This establishment provides fast and economical certification as a service for everyone.

DKD calibration certificates can be issued for resistance thermometers, thermocouples, direct-reading measurement sets, data loggers, temperature block calibrators and temperature probes with built-in transmitters, within the range –80 to +1100 °C. The traceability of the reference standard is the central issue here. All DKD calibration certificates are therefore recognized as documents of traceability, without any further specifications. The DKD calibration laboratory at JUMO has the identification DKD-K-09501-04 and is accredited to DIN EN ISO / IEC 17 025.

You can get a free brochure (at present only available in German) by asking for Publication No. PR 90029 or as a download from www.jumo.net.

Practical assistant for everyday use

"Standard values for thermocouple and resistance thermometers"

at present only available in German

This is a practical assistant for use in laboratories, production, service and training, and includes the standard reference values for thermocouple types J, K, T, N, S, R and B as per EN 60 584 and for Pt 100 resistance thermometers according to EN 60 751.

It enables you very quickly to assign a temperature value to every resistance value or thermal emf - or the other way around.

The pocket slide-rule, the interchangeable tables of data, color-coded according to the elements, and the corresponding operating instructions are all in wipe-down plastic. And everything is held in a clear plastic pocket, to prevent it becoming dirty.

The WINDOWS calculation program (on a diskette) generates the standard values according to freely selectable temperature limits and increments. These tables can also be exported for further processing in other applications.

In addition, the resistance value, thermal emf and tolerance class (as defined by the standard) can all be determined for any value of temperature. Alternatively, the corresponding temperature can be calculated from the known value of the sensor signal.

Furthermore, the individual characteristic curve parameters for resistance thermometers can be programmed and saved. All the usual calculation options are provided for this purpose.

Pocket slide rule

To be ordered under Sales No. 90/0034111. (Article only available in German at present)

3 ½" diskette version

To be ordered under Sales No. 90/00341183 or as a download from www.jumo.net (Article only available in German at present)

Schools, institutes and universities are asked to make joint orders, because of the high handling costs.

Fig. 20: Pocket slide rule and WINDOWS program
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