
testo 454 Measuring system in use at WENZEL Precision

# Temperature as a process parameter

**Temperature is an increasingly important parameter in industrial manufacturing. As temperature fluctuations cause changes in length, high-precision manufacturing is only possible with accurate temperature measurements.**

The basic factor determining temperature is the degree of molecular movement. With increasing thermal movement, the space occupied by the molecules grows, which is why virtually all bodies expand when heated. For industrial manufacturing, temperature therefore has physical implications for the validation of measurement results. In light of increasing quality and accuracy demands, temperature control in production processes is becoming more and more important. Faster processing and increasingly compact products with small components occupying the minimum of space require more intensive monitoring of temperatures and the associated changes in dimensions. The temperature of complex components made from different materials and of different thicknesses must be measured at different points simultaneously in order to achieve definable processing conditions with an even temperature distribution. Temperature is becoming an increasingly important parameter for determining the degree of material expansion in machine and system components and in workpieces. Testo offers a range of different solutions which are relied upon by the company Wenzel Precision GmbH, a respected manufacturer of coordinate measuring machines for various tasks.

**Leaders in the manufacture of coordinate measuring machines**

WENZEL Precision has been a leading light for 30 years in the development of measurement technology for mechanical, electronic and optical parts. The company, headquartered in Wiesthal/Spessart, Germany, is one of the world's leading manufacturers of coordinate measuring machines. Its product range covers measuring instruments in portal and pillar designs, both with horizontal air bearings and with roller bearings on base plates and guide

## DKD lab

# surface temperature

In a collaborative project with participants from the Technical University of Ilmenau, the PTB (German Federal Institute for Physics and Technology) and two other DKD labs, a calibration station was established for contact surface probes. The calibration devices can be used to calibrate surface temperature probes of different designs on horizontal surfaces of different materials. Currently, test specimens made from stainless steel, copper and aluminium are routinely available. The calibration range of the installation extends from +50 °C to +500 °C. The smallest measurement uncertainty is 0.8 % of the set temperature, but with a minimum value of 0.8 K. Since the beginning of 2000, Testo has been accredited as the first DKD lab for surface temperature probes.

beams. The measuring ranges are between 500 x 600 x 400 mm and 10,000 x 4,000 x 3,000 mm for the smallest air-supported machine and 12,000 x 3,000 x 2,500 mm for the largest normally available roller-supported system. Custom solutions have already been realised for measurements of up to 40 m on the x-axis. To create solutions for specific applications, the systems can be equipped with different touch probes. The measurement and evaluation software packages originate from the Swiss subsidiary company METROMEC Software AG and are therefore also available in-house.

**Temperature as a controlled variable**

WENZEL coordinate measuring machines are used in virtually all areas of high-precision mechanical production. Temperature measurement is of fundamental importance here. As is standard in measurement technology, dimensions and tolerance specifications are based on a reference temperature of 20 °C. In order to determine changes in length at differing temperatures and to be able to compensate for this, reliable and accurate temperature measurements are required for the mechanical components of both the measuring instrument and the test specimen. A temperature change of only two degrees can, for example, cause a change in length of 23 µm per metre of measured length for steel. This indicates the significance of temperature recording as a controlled variable that must be considered when evaluating measurement results.

**Temperature distribution in granite blocks**

In this field, WENZEL uses Testo measuring instruments for various tasks. This begins with the manufacture of the coordinate measuring machines. Another application is the processing of granite blocks for high-precision air bearings. Here, the surfaces are lapped to micrometre tolerances and sometimes even down to the sub-micrometre level. This takes place in air conditioned areas where the ambient temperatures are sometimes maintained at tolerances of 0.2 K. The testo 454 measurement systems used here record the temperature distribution in the granite blocks being processed. Processing can only begin once an even temperature distribution has been reached in the granite block after an appropriate length of time spent in the air conditioned room with a maximum variation of 0.2 to 0.3 °C. Different temperatures, for example on the top side and underside, would produce a kind of bimetal effect with the corresponding changes in dimensions. The measurements are taken at various points simultaneously and at programmed intervals. Surface probes are applied for this purpose, and are connected to decentralised data loggers for recording the measurements. PCMCIA interfaces are used for data exchange via the Testo data bus to the computer. Online measurement allows the measurements from different loggers to be displayed easily and clearly on one screen.

The uses for the testo 454 measurement sytems also include monitoring the ambient temperature of the air conditioned production areas.

Similarly, Testo systems are used in the construction of measuring machines and for installation and approval on the user's premises. The combination of a control unit for the visualisation of measurement data and a system control with decentrally positioned data loggers for collecting and saving the measurement data allows multiple measurements to be recorded flexibly with simultaneous measuring at multiple sites.

## Contact or non-contact measurement?

There are basically two main methods used for contact temperature measurements on objects:

- penetration/immersion measurements or
- air temperature measurements.

There are some applications where contact measurement is the most suitable method for measuring surface temperatures while there are other applications where non-contact temperature measurement has proven to be more suitable. A combination of both methods in one instrument is often found to be ideal.

**Classical contact applications**

1. Objects with high heat capacity
– Metals
– Large metal masses

2. Objects with smooth surfaces
– Polished steel plate
– Polished heating pipes

**Thermocouples**

Temperature measurement using thermocouples is based on the thermoelectric effect. Thermocouples consist of two wires welded together. The wires are made of different metals or metal alloys. The basic values of the thermoelectric voltages and the maximum tolerances in thermocouples are defined in the IEC 584 standards. The most common thermocouple is NiCr-Ni (type designation K).

**Resistance sensors (Pt100)**

When measuring temperature with resistance sensors, use is made of the temperature sensitive resistance change in the platinum “resistance”.

The measurement resistance is supplied with a constant current and the voltage drop, which changes with the resistance value via the temperature, is measured. Basic values and tolerances for resistance thermometers are defined in the IEC 751.

**Thermistoren (NTC)**

Temperature measurement with thermistors is also based on a temperature sensitive change in the resistance of the sensor element. Unlike resistance thermometers, thermistors have a negative temperature coefficient (resistance decreases with increasing temperature). Properties and tolerances are not standardised.

**Rule-of-thumb**

Thermocouple probes are quick and have a wide measuring range. Resistance and NTC probes are slower but more accurate.

The wider the measuring range the more universal the applications.

**Measurement range**

First cross off the probe type which does not apply to your measuring range. The diagram below shows the application range of different temperature sensors.

## Selecting the right probe

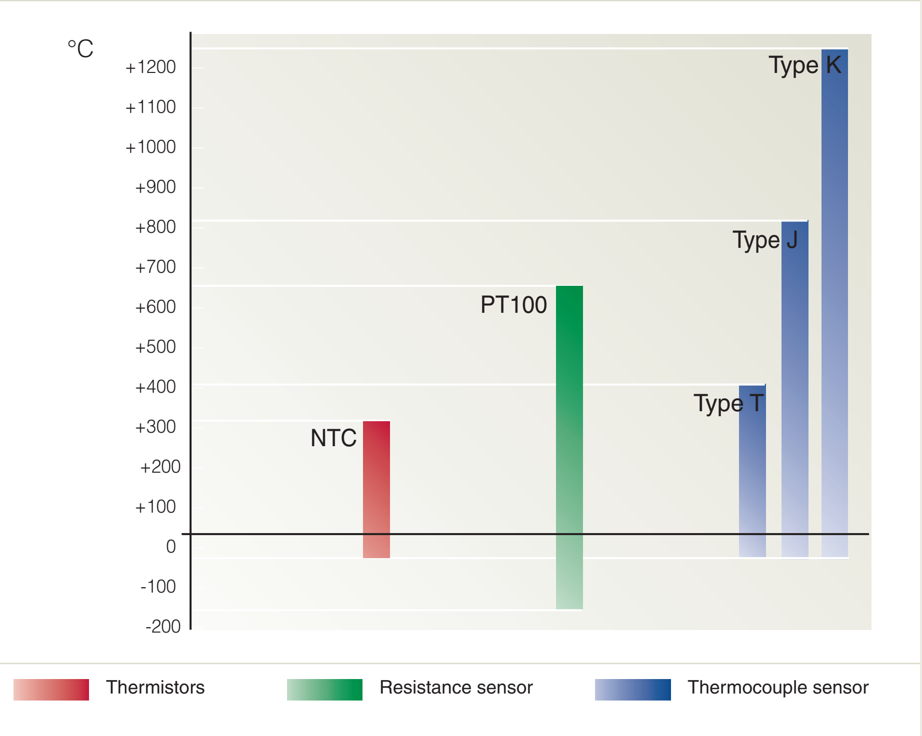
The probe type is determined by the measuring task. The suitable temperature sensor is selected according to the following criteria:

- Measuring range
- Accuracy
- Design
- Response time
- Resistance

Testo has a range of sensor elements and thermometers available in order to be able to supply the probes needed for your applications:

- Thermocouple sensor
- Resistance sensor (PT 100)
- Thermistors (NTC)

**Temperature measurement: Thermocouples**



## Contact measurement

### Accuracy

Select the sensor with the accuracy required for your application from the diagram or table.

**Accuracy**

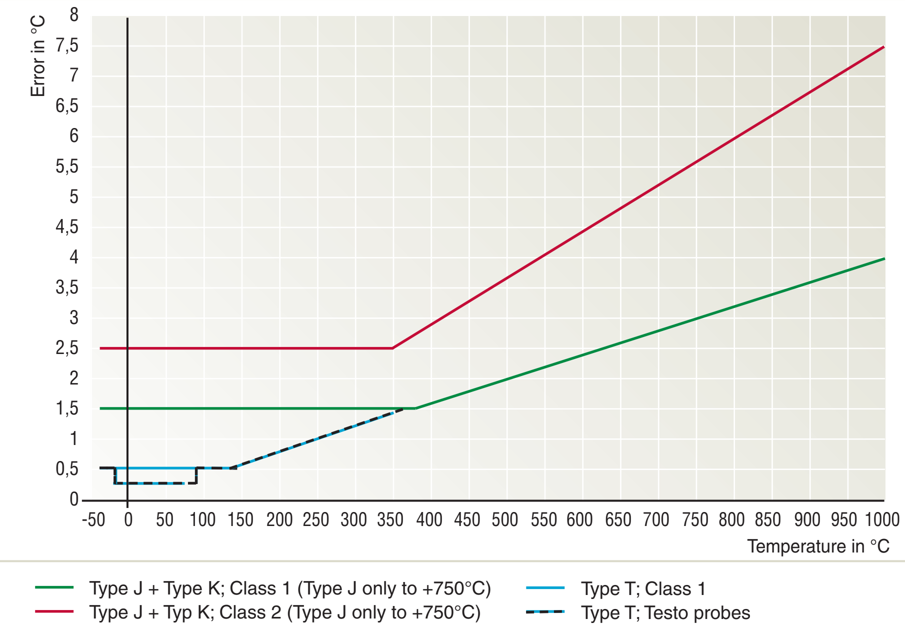
| Sensor | Temperature range | Class | Maximum tolerances: Fixed value | Maximum tolerances: Referred to temperature |
|---|---|---|---|---|
| **Thermocouple** Type K (NiCr-Ni) | -40 to +1200 °C | 2 | ±2.5 °C | ±0.0075 x ltl |
| | -40 to +1000 °C | 1 | ±1.5 °C | ±0.004 x ltl |
| Type T | -40 to +350 °C | 1 | ±0.5 °C | ±0.001 x ltl |
| Type J | -40 to +750 °C | 1 | ±1.5 °C | ±0.004 x ltl |
| **Pt100** | -100 to +200 °C | B | ± (0.3 + 0.005 • ltl) | |
| | -200 to +600 °C | A | ± (0.15 + 0.002 • ltl) | |
| **NTC** (Standard) | -50 to -25.1 °C<br>-25 to +74.9 °C<br>+75 to +150 °C | – | ±0.4 °C<br>±0.2 °C<br>±0.5 % of reading | |
| **NTC** (High temp.) | -30 to -20.1 °C<br>-20 to 0 °C<br>+0.1 to +75 °C<br>+75.1 to +275 °C | –<br><br><br>– °C | ±1 °C<br>±0.6 °C<br>±0.5 °C<br>±0.5 °C ±0.5 % of reading | |

t = Measured temperature

Data for thermocouples to EN 60584-1 (formerly IEC 584-1). Two values are given. One fixed value in °C and one formula.

The larger value always applies. Data for Pt100 to EN 60751 (formerly IEC 751). There is no standardization for NTC sensors.

**Accuracy: Thermocouple**

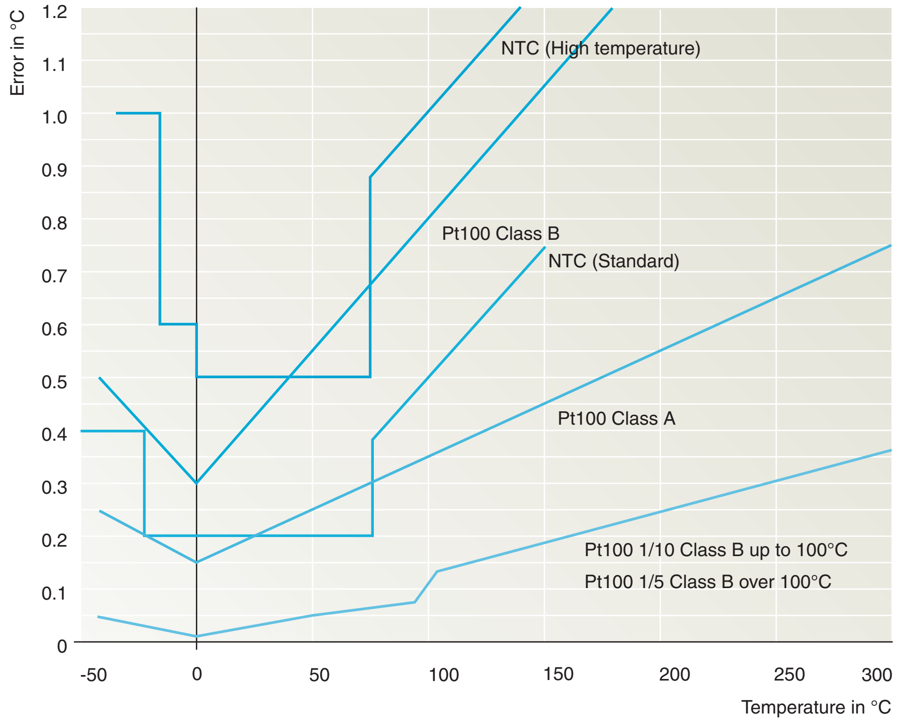



**High accuracy also with thermocouples**
Testo uses specially selected material for Type T thermocouples in the range -20 to 70 °C to achieve a high accuracy level of ± 0.2 °C in this range.

**High accuracy**

testo 950 has easy, menu-driven operation of the highest accuracy. In addition to rapid-action and reliable thermocouple probes, Pt100 probes, corresponding to EN 60751 (formerly IEC 751) , or selected high precision probes on a Pt100 basis with 1/10 DIN accuracy can be connected. When compared to “standard” precision probes with their highly accurate Pt100 sensors, these precision sensors are 10 times more accurate. When referred to Class B which has an error of ±0.3 + 0.005 x I Temperature I, this infers an error of only ±0.03 + 0.0005 x I Temperature I.

**Pt100/NTC accuracies**




## Which sensor is needed for which instrument?

You can now select which instruments can be used for your application by choosing the suitable sensor type or types based on measuring range and accuracy. Some of the Testo instruments have other functions, in addition to displaying readings, which help you solve your measuring task. Select the functions which are important to you and the corresponding instrument from the product pages.

**Overview of all Testo thermometers**

| | Monitoring instruments | | | | | | Reference instrument | Data loggers | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | testo 720 | Ex-Pt 720 | testo 925 | testo 922 | testo 935 | testo 945 | testo 950 | testo 175-T3 | testo 177-T4 | testostor 171-0 | Ex 171-0 | testostor 171-4 | testostor 171-8 |
| Thermocouple - Type K | | | ✘ | ✘ | ✘ | ✘ | ✘ | ✘ | ✘ | | | | ✘ |
| Thermocouple - Type T | | | | | ✘ | ✘ | ✘ | ✘ | ✘ | | | | ✘ |
| Thermocouple - Type J | | | | | ✘ | | ✘ | | | | | | |
| Pt 100 /1/10 DIN | | | | | | | ✘ | | | | | | |
| Pt 100 | ✘ | ✘ | | | | ✘ | ✘ | | | | | | |
| Thermistor (NTC) | | | | | | ✘ | ✘ | | | ✘ | ✘ | ✘ | |
| Integrated probe | | | | | | | | | | ✘ | ✘ | | |
| Highly accurate meas. | ✘ | ✘ | | | | ✘ | ✘ | | | | | | |
| Ex-proof | | ✘ | | | | | | | | | ✘ | | |

## How to find the right probes for the instruments:

**Response time:**

| | |
|---|---|
| **t99 time =** | **Time needed for probe to show 99% of change in temperature** |
| **t99 =** | **4.6 x t 63 - Time** |
| **t99 =** | **2 x t 90 - Time** |

**Immersion/penetration probe:**

Immersion probe (NiCr-Ni, Pt100, NTC) for measurements in liquids but also for measurements in powdery substances or in air.

Penetration probe (NiCr-Ni, Pt100, NTC) for measurements in plastic or semi-solid environments

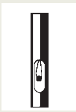
**Additional information**

- The specified response time of t99 is measured in moving liquid (water) at 60 °C.
- Generally, the thinner the probe, the quicker it is and the less it has to be immersed in the object being measured.
- The probe has to be immersed at least 10 x the probe diameter into the object being measured (15 x diameter is better) in order to determine the real temperature.
- However, the thinner a probe is, the more careful you have to be with the probe.
- Thermocouple probes can be produced with a very small diameter (0.25mm) and are therefore ideal for quick measurements and for measurements on small objects.
- Only resistance sensors with a diameter of 2 mm can be produced at a low cost. They are usually more accurate than thermocouple probes.

**Probe Materials**

The probe pipe in the thermocouple immersion probes is made of Inconel (2.4816). Stainless steel V4A (1.4571) is used for the probe pipe in all other designs. Resistance to corrosive substances is usually sufficient on account of the high standard of the material used. Testo has glass-coated probes for use in highly corrosive agents.

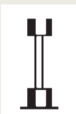
**Air probe**



(NiCr-Ni, Pt100, NTC)
The sensor usually lies bare to facilitate rapid measurements.

- The specified response time t99 is measured in the wind tunnel at 2 m/s and 60 °C.
- Immersion/penetration probes can be used for air measurement. The response time is 40 to 60 times higher than the specified value measured in water.

**Surface probe**



Design in NiCr-Ni, Cu-CuNi; PT100; NTC probes. With widened measuring tip for measurements on smooth, flat surfaces. We recommend silicone heat paste (Tmax 260 °C) for an optimum heat transfer.

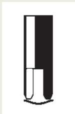
Advantages:

- Robust design
- Higher sensor accuracy

Disadvantages:

- Slow response time
- Accurate handling required

Only suitable for smooth surfaces and objects with a high heat capacity e.g. large metal objects.



Design of Ni Cr-Ni probes

We recommend the patented cross-band measuring head with spring-loaded thermocouple for quick measurements, also on rough surfaces. The cross-band determines the actual temperature of the object being measured within seconds:

- Easy handling (without silicone heat paste)
- Quick results

**Additional information**

- The given response times of t99 are measured on polished steel plates at 60 °C
- The specified accuracies are sensor accuracies.
- The accuracy in your application depends on the condition of the surface (roughness), material of the object being measured (heat capacity as well as heat transfer) as well as the sensor accuracy. If you wish to know the deviations of your measuring systems, you can have a calibration certificate issued by Testo. Testo has developed a surface test rig together with the German Federal Physical and Technical Institute (Physikalisch Technische Bundesanstalt) for this purpose.

Testo is therefore one of the first manufacturers able to issue DKD and ISO certification for your applications. Further information on page 310.

The demand for a highly accurate temperature measurement system came mainly from sectors involved with quality assurance, calibration services and laboratories. This demand is accommodated by a revolutionary highly accurate immersion/penetration probe with a system accuracy of up to 0.05 °C.

| System measurement uncertainty | |
|---|---|
| Probe measurement uncertainty | Instrument meas. uncertainty |

The overall system measurement uncertainty of temperature measurement in conventional measuring instruments is made up of the measurement uncertainty of both the instrument and the probe. The instrument measurement uncertainty results mainly from the analog measurement technology to analyse the probe signal, analog-to-digital conversion, linearisation and resolution. The probe measurement uncertainty is determined by the precision of the temperature sensor used.

| System meas. uncertainty | |
|---|---|
| Probe meas. uncertainty | |

The new, highly accurate measurement system from Testo eliminates instrument uncertainty and reduces probe measurement uncertainty. Technologically, it is based on the following components:

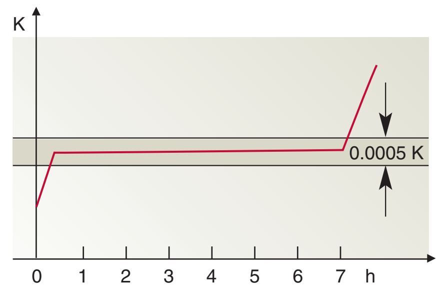
**Intelligent probe**

The reading is processed completely in the probe from the analog sensor signal to the digital reading. The overall instrument measurement uncertainty therefore does not apply.

**Individual probe adjustment**

Since each reading is processed completely in the probe, each probe is adjusted separately using highly accurate fixed point cells.

Adjustment with fixed point cells




At the melting/solidification point, the fixed point cells used keep the temperature constant over a longer time period in the 0.0005 K range. The immersion/penetration probe is adjusted in this phase.

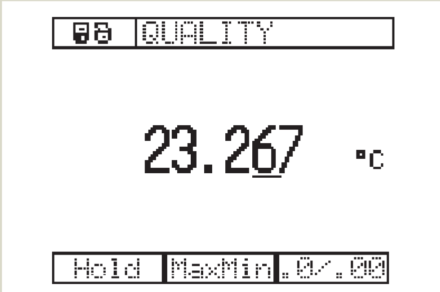
**Platinum sensor**

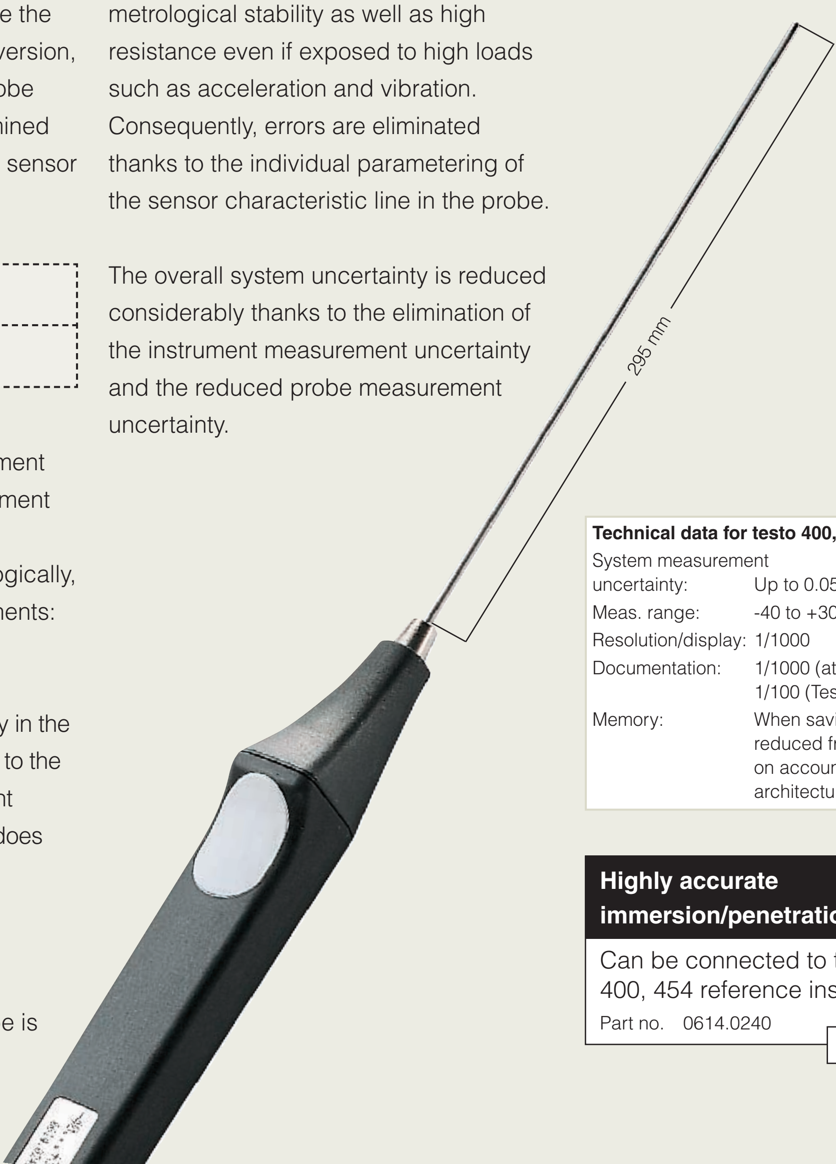
A specially developed platinum wire, integrated in a high-purity aluminium oxide pipe, guarantees highest accuracy, metrological stability as well as high resistance even if exposed to high loads such as acceleration and vibration. Consequently, errors are eliminated thanks to the individual parametering of the sensor characteristic line in the probe.

The overall system uncertainty is reduced considerably thanks to the elimination of the instrument measurement uncertainty and the reduced probe measurement uncertainty.

There are even more system advantages in addition to highly accurate temperature measurement:

- System accuracy independent of instrument and socket: the highly accurate immersion/penetration probe achieves full accuracy regardless of the probe socket used.
- Highly accurate differential temperature measurements are thus possible with all multi-channel measuring instruments.




**Technical data for testo 400, 650, 950**

| | |
|---|---|
| System measurement uncertainty: | Up to 0.05 °C |
| Meas. range: | -40 to +300 °C |
| Resolution/display: | 1/1000 |
| Documentation: | 1/1000 (attachable printer)<br>1/100 (Testo printer) |
| Memory: | When saving the resolution is reduced from 1/1000 to 1/100 on account of the memory architecture |

**Highly accurate immersion/penetration probe**

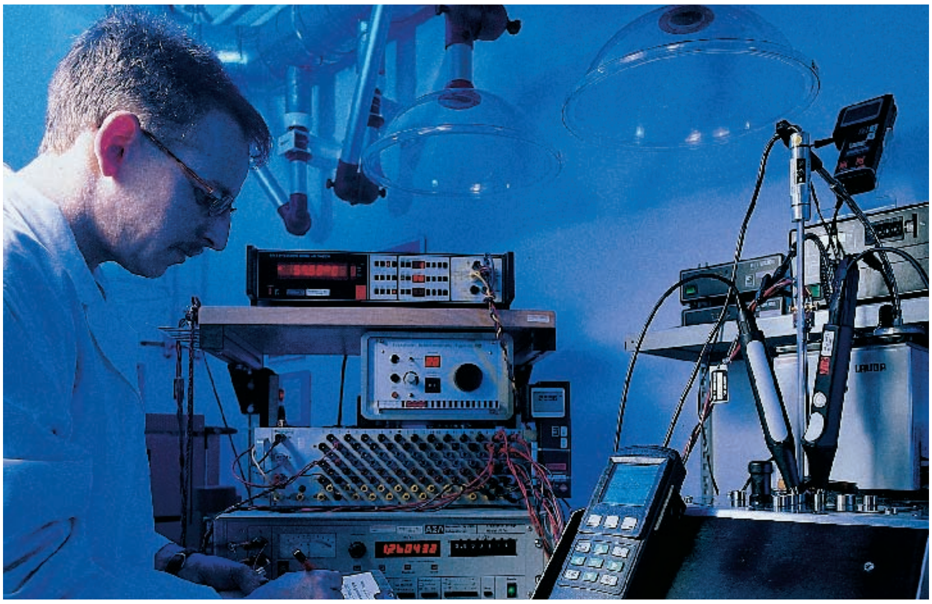
Can be connected to testo 950, 650, 400, 454 reference instruments

Part no. 0614.0240

## Industrial calibration procedures: temperature

Testo received the first accreditation for its temperature lab in as early as 1994. The range of accreditation services has been continuously expanding ever since. For all calibrations, traceability to a national standard and the calculation of measurement uncertainty is guaranteed.


DEUTSCHER KALIBRIERDIENST DKD
PHYSIKALISCH-TECHNISCHE BUNDESANSTALT (PTB)
CAL
Testo CAL



**Immersion probe:**
Comparative measurement: the preferred calibration method for measuring instruments with immersion probes is comparative measurement using a reference device or operating standard in a liquid or a tube furnace. The following factors should be observed:
– Penetration depth (at least 15 x probe diameter)
– Adjusting time
– Temperature fluctuations in the liquid/air
– Spatial temperature distribution in the liquid/air space
– Inherent warming of the test specimen.

Fixed point calibration: The best-known fixed points, which have been used for hundreds of years, are the freezing and boiling points of water. Even today, the freezing point applied to distilled water is a commonly used reference point for laboratory calibration of thermometers. In principle, any fixed point defined by ITS-90 could be used, but the procedure for applying them is often too complex. In addition, the levels of measurement uncertainty demanded by industry do not require high-precision fixed point cells. The most commonly-used point in labs is the triple point of water at 0.01 °C.

**Surface probes:**
Surface probes are calibrated on a standardised heating/cooling plate, just like in everyday applications. Only then is the measurement process taken into account in the calibration. Submersed calibration in a liquid pan is not advised.

**Infrared probe:**
The calibration of an IR temperature measuring device is carried out on a “black body radiator”. The radiation temperature is generated using a heating system or a tempered liquid pan depending on the generator design.

**Air probe/data logger:**
The best method for calibrating these designs is by using circulating air, as provided in a temperature or conditioning cabinet. The spatial temperature distribution in the test room needs to be determined using a wide range of measurements.

**Excerpt from the accreditation documentation for DKD laboratory 11201**

| Parameter/ object to be calibrated | Measuring range | Meas. conditions | Measurement uncertainty |
|---|---|---|---|
| **Temperature** electrical resistance thermometer and electronic thermometer | 0.00 °C | Freezing point | 10 mK |
| | 0.01 °C | Water triple point | 5 mK |
| | -80 °C to 0 °C | Liquid bath with equalisation block | 20 mK |
| | > 0 °C to 100 °C | | 10 mK |
| | 100 °C to 200 °C | Silicone oil bath | 30 mK |
| | 200 °C to 400 °C | Salt bath | 30 mK |
| | 400 °C to 500 °C | | 50 mK |
| | 500 °C to 660 °C | Tube furnace with Na heat pipe | 0.2 K |
| Non-precious metal thermal elements | -80 °C to 200 °C<br>> 200 °C to 400 °C<br>> 400 °C to 500 °C | Thermostatic baths | 0.2 K<br>0.4 K<br>0.5 K |
| | > 500 °C to 1,000 °C | Tube furnace with Na heat pipe | 1.0 K |
| Surface temperature probes | 50 °C to 100 °C | | 0.8 K |
| | > 100 °C to 500 °C | | 0.008 K · t / °C |
| Temp. meas. instruments | -30 °C to 0 °C<br>> 0 °C to 50 °C<br>> 50 °C to 80 °C<br>> 80 °C to 120 °C | in temperature-controlled cabinet | 0.32 K<br>0.34 K<br>0.52 K<br>0.84 K |