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Reliable measuring results in any temperature

Avoidance of measurement errors through temperature compensation

Werth Messtechnik GmbH

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PRACTICAL TIP Deviations from the reference temperature can cause large measurement errors. The recording of the temperature enables a mathematical compensation of the thermal effects on the coordinate measuring machine. This results in a much more cost-effective alternative to a high-precision air-conditioned measuring room.

Johannes Bieber

TEMPERATURE DEVIATIONS are one of the many different components of measurement uncertainty. Machine, scale, and workpiece temperature have a direct influence on the measurement result. Deviations of the room temperature from the reference temperature of 20 °C have an indirect effect on these temperatures. Additional influencing factors are the residual heat of the workpiece (e.g. from processing and handling), as well as heat sources in the measuring device (e.g. motors, light sources). Temporal temperature gradients cause a drift of the measuring results.

The primary thermally induced sources of measurement uncertainty are the linear expansion of the workpiece and the scales with increasing temperatures. Other thermally induced measurement errors are caused by the deformation of the measuring device and by the change in length of the stylus during tactile measurements. These effects are not corrected in most devices.

The magnitude of the measurement deviation varies depending on the thermal expansion coefficient of the workpiece material. A temperature correction of the measurement results is necessary only if the reference temperature is maintained during the entire measurement. This means that a constant temperature of 20 °C is maintained for both the entire coordinate measuring machine (CMM) and the workpiece.

Thermally induced length change

The greater the thermal expansion coefficient of the material α the length of the workpiece L0 and the temperature deviation ΔT from the reference temperature, the greater the thermally induced length deviation ΔL:

$$\Delta L = \alpha \cdot L_0 \cdot \Delta T$$

Without temperature compensation, for example, the length measurement of a 100 mm long PVDC workpiece at 25 °C and scales on steel supports results in a measurement error of approximately 70 µm.

As the temperature increases, the workpiece expands and the measurement error increases. Since the scales also expand, the measuring deviation is partially compensated (Fig. 1). Therefore, in the above example, the change in length of the scales on steel carriers was subtracted from that of the workpiece. If workpieces made of the same material as the scales are measured, the expansion effects compensate each other provided that the same temperature conditions prevail on the scales and the workpiece. However, this method has two disadvantages: First, it is rather rare in practice that the temperatures of the scales and the workpiece exactly match, and second, only workpieces made of the same material as the scales can be measured in this way.

Scales made of special ceramics have a coefficient of thermal expansion close to zero, so that only the expansion of the workpiece has to be taken into account. This

Measuring length: 100 mm Coefficient of expansion Standards: like steel		Temperature			
		20 °C	25 °C	30 °C	35 °C
Material	**Expansion coefficient α in µm / m K**	**Mean systematic measurement error of the length ΔL in µm**			
PVDC	150,0	0	69,3	138,5	207,8
Polyamide	100,0	0	44,2	88,5	132,8
Aluminium	24,0	0	6,3	12,5	18,8
Steel	11,5	0	0	0	0

Table 1: Temperature-dependent systematic measurement deviation of the length without correction at the same temperature on workpiece and scales (© Werth)

alone, however, is not an optimal solution for compensating the thermally induced measuring deviations. This is because without mathematical temperature correction, the error caused by the expansion of the workpiece will be greater if the scales do not also expand. The mathematical correction of the thermal influence is absolutely necessary here if it cannot be ensured that the workpieces are measured exactly at 20 degrees.

Specification for real environmental conditions

For each coordinate measuring machine, the manufacturer specifies a maximum permissible length measurement deviation under defined conditions. These conditions also include the temperature interval in which the device operates within the given specifications. The specifications usually apply to temperature deviations of ± 2 K from the reference temperature of 20 °C in the measuring room. Some manufacturers guarantee a higher performance of the measuring instrument for more stable temperature conditions by specifying a lower maximum permissible length measurement deviation, for example, for temperature fluctuations of only ± 1 K.

Few manufacturers offer specifications for operating the instrument in a non-air-conditioned environment, for example for in-process measurements. In this case, the specified maximum permissible length measurement deviation should be valid at least for a temperature interval between 16 °C and 30 °C. Please note that this specification should not be restricted by the manufacturer to standards with a coefficient of expansion = 0. Such a specification would be of little practical use, since hardly anyone measures workpieces with this property.

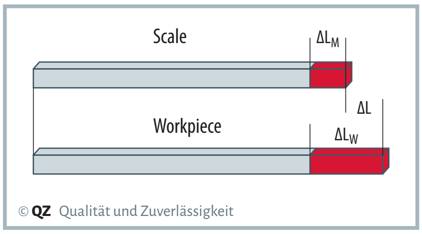

Figure 1: **The expansions of the scale and the workpiece cancel each other out partially.**
(Source: Werth)

Temperature sensors on the scales are standard equipment for all Werth coordinate measuring machines. With the help of the thermal expansion coefficient of the scale material, the linear expansion is mathematically corrected.

Mathematical correction of temperature-related measurement deviations

For instruments with particularly small measuring deviations (HA - High Accuracy and UA - Ultra Accuracy), scales made of special ceramics are used. These devices are usually installed in air-conditioned rooms despite mathematical temperature correction. For an exact determination of the coefficient of expansion, a complex calibration on the workpiece might be necessary. The uncertainty of the mathematical temperature correction caused by the calibration uncertainty of the expansion coefficient could otherwise also increase the temperature-related measurement deviations at larger temperature differences. Air conditioning also avoids the other effects mentioned above (distortion etc.).

When using the coordinate measuring machine in the production environment, it is possible to measure the temperature additionally in the measuring volume or directly on the workpiece. The latter variant provides the more accurate results, but is more complicated for the operator. The thermal expansion coefficient for the different materials can usually be taken from tables or can be determined by calibration. After entering the coefficient of expansion for the respective workpiece material, the WinWerth measuring software calculates the expansion of the workpiece and corrects the measured values accordingly.

Workpiece temperature compensation is essential in the production environment and in measuring rooms with minimal or no air conditioning. Workpiece temperature compensation must also be used for workpieces with tight tolerances or for long distances where the temperature-related length change is more significant.

This can be easily retrofit to Werth instruments and guarantees operation of the instrument within the given specifications in a temperature range of 16 °C to 30 °C. If workpiece temperature compensation is additionally used in the measuring room (in case of temperature fluctuations of ± 2 K), the image processing sensor or conventional touch probes, achieve the same maximum permissible length measurement deviation as with deviations of only ± 1 K from the reference temperature. ■

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