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Controlling Temperature Effects on Dimensional Measurements – Overview and new Approaches

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Abstract

Temperature might be the most sensitive influence for dimensional measurements in industrial production because of thermal expansion of most materials used. Therefore, the temperature environment conditions and the workpiece temperature need to be observed carefully. The observation results are used to correct the thermal expansion of the workpiece considering certain constrains and to assure that the environment temperature does not exceed these constrains. Active climatization of workpieces helps to accelerate the measurement of work pieces heated by manufacturing.

Dimensional Metrology, Temperature Metrology, Climatization

1. Introduction

Temperature might be the most sensitive influence for dimensional measurements in industrial production because of thermal expansion of most materials used. The standards for Geometrical Product Specification define in ISO 1 the standard reference temperate to 20°C [1]. Most production facilities do not provide an environment with a constant temperature of 20°C. Furthermore, manufacturing processes heat up the product to be measured. Therefore, dimensional measurements are perfumed at temperatures that are different to 20°C and results must be corrected depending on temperature and thermal expansion.

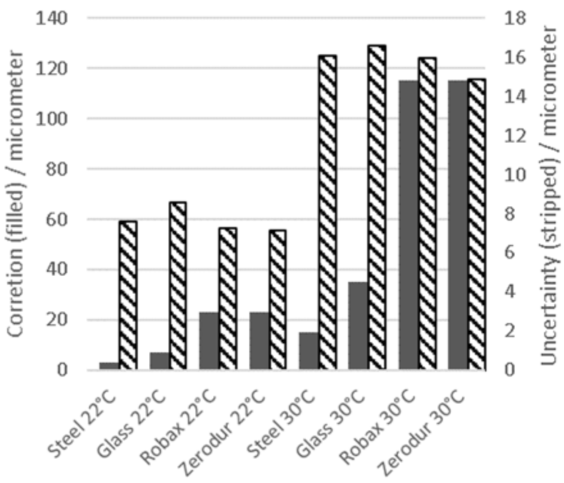

Figure 1. Correction and its uncertainty for measuring 1m length on a steel workpiece with different scale materials at 22 and 30°C

Most corrections are made based on a linear expansion model. The details of the correction calculation considering also the expansion of the used scale are describe in ISO/TR 16015 [2]. Moreover, this standard includes the determination of the corresponding uncertainty for the correction. Figure 1 shows example values of correction and uncertainty for measuring 1 m length on a steel workpiece (Coefficient of Thermal Expansion CTE=11.5*10-6 /K) with different scale materials considering information from [2-5].

The corrections for steel scales are the lowest one because thermal expansion of scale and workpiece compensate each other. Nevertheless, the lowest uncertainty is achieved using temperature insensitive material made of glass ceramic like Robax or Zerodur from Schott AG, Germany.

A closer look on the distributors to the uncertainty of the correction shows the dominating impact of workpieces's thermal expansion. The contribution of the scale in case of insensitive material is close to zero except for Robax scale due to its uncertain CTE (Figure 2) [6].

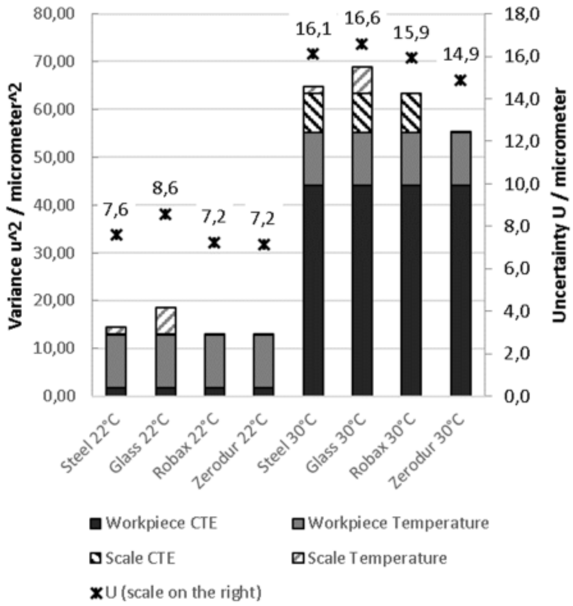

Figure 2. Uncertainty of correction for measuring 1m length on a steel workpiece with different scale materials at 22 and 30°C (The uncertainty is calculated from the square root of the linear combination of the different component's variances [2, 7]. Therefore, the variances are used here for the presentation of component's contribution in the bars.) [6]

2. Supervision of Temperature Conditions

Nevertheless, the performance of complex measuring systems for dimensional measuring tasks like Coordinate Measuring Machines (CMMs) cannot be described by the scale expansion only. Therefore, the manufacturers specify operating conditions for their system. In case of CMMs a temperature range and limits for spatial and temporal thermal gradients are defined. The supervision of these operating conditions requires a temperature measuring system with several sensors that combines the results from the different sensors to determine the gradients. The installation setup of the sensors depends on the individual CMM location and its environment conditions. Recommendations for the setup are available in German guideline VDI/VDE 2627 [8, 9], which also classifies the environment in relation to the temperature stability. The data from the sensors are recorded and a dashboard presents the results and indicates warnings in case of limit violations (Figure 3).

Figure 3. Dashboard of the temperature supervision system TEMPAR from ZEISS with visualisation of temperature and temperature gradients

3. Workpiece Temperature Recording and CTE Calibration

A prerequisite for correction of length temperature is the precise determination of workpiece's temperature. Different types of contact sensors are used for that purpose. Pallet integrated sensors with spring force contact are used for automatic loading. Also, the CMM itself can carry an automatic changeable temperature sensor instead of the dimensional sensor (Figure 4).

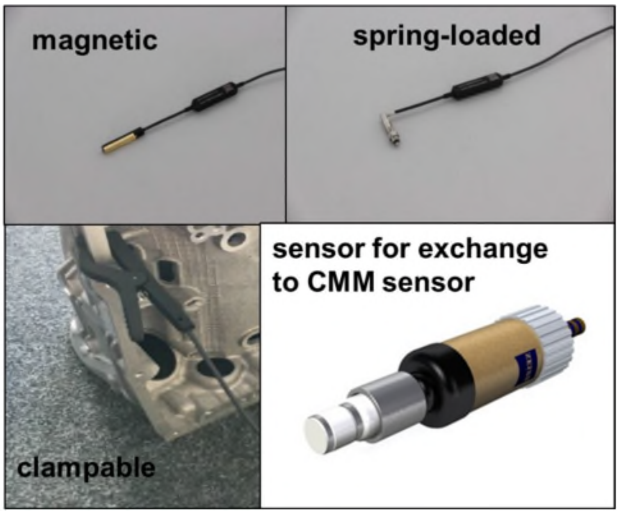

Figure 4. Sensors for workpiece's temperature recording

The recorded temperature data are used for correction as described above. This correction is a static correction and does not consider any gradients. This is an issue for measuring systems like CMMs that measure characteristics consecutively. The implementation of a dynamic correction does not seem possible due to the complex relationship between the consecutively measured characteristics and corresponding dates.

Beside the precision of workpiece's temperature measurement, the CTE (Coefficient of Thermal Expansion) influences the uncertainty of thermal expansion correction significantly. The variation of CTE among several heat treatments of the same steel reaches up to 10% [2]. Therefore, the calibration of CTE (Figure 5) may reduce the uncertainty of the thermal correction.

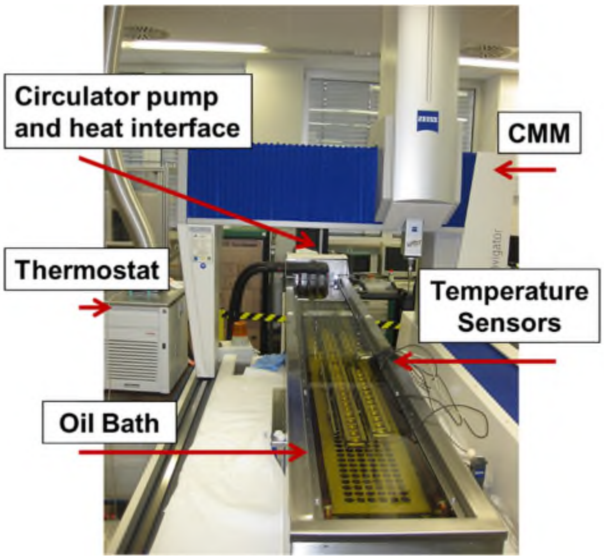

Figure 5. Calibration for coefficients of thermal expansion (CTE) at ZEISS's calibration lab

4. Active Climatization for Workpieces

Workpieces that come directly from machining are often heated up by the process. Afterwards they cool down and adapt to the ambient temperature. The cooling process can take several hours (Figure 6).

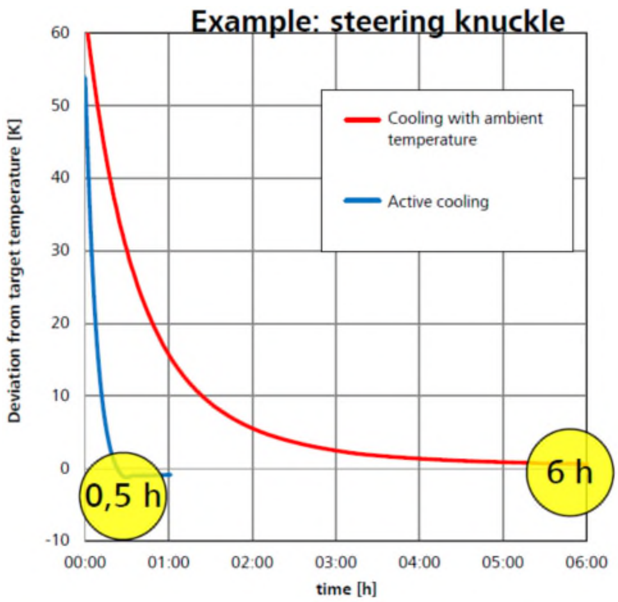

Figure 6. Cooling curves with and without active air conditioning

If a largely constant temperature is not reached measuring is not possible, because the dimensions of the workpiece are constantly changing, which cannot be compensated with static corrections. This delays rapid feedback to manufacturing. Using an active climate chamber (Figure 7) this time can be reduced dramatically. The coloured lighting shows workpiece's temperature gradient. Green indicates that the workpiece is ready to measure.

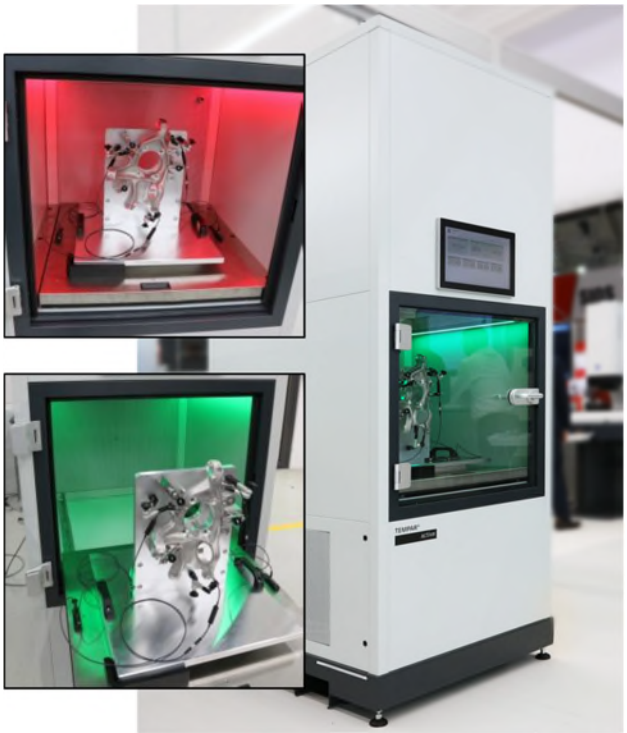

Figure 7. Active climatization for workpieces ("Zeiss TEMPAR active")

5. Summary and Outlook

The magnitude of workpieces' thermal expansion in industrial production reaches typical tolerances. Therefore, precise thermal expansion correction plays an important role in measuring dimensional characteristics. Beside accurate measurement of workpiece's temperature, calibration of workpiece's CTE and supervision of environment temperature to assure of specified operating conditions for measuring system, active workpiece climatization can accelerate the dimensional measurement process.

New ideas for more accurate thermal expansion correction may improve the accuracy of the correction [10]. But the effort increases dramatically.

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