Whitepaper: Temperature Fluctuations

Small Changes with Big Impact

Temperature Fluctuations

Small Changes with Big Impact

"The most important thing is to observe temperature limits" – that's what many users of coordinate measuring machines think, anyway. Unfortunately, a bit more care is required to avoid incorrect measurements. This white paper explains why people often underestimate the effects of temperature fluctuations and what you can do to prevent measurement errors.

At many production sites, coordinate measuring machines (CMMs) are standard equipment for precise manufacturing and outstanding quality. When it comes to the accuracy of the measurement results, temperature plays a pivotal role. Sometimes the measuring machines are located directly on the production floor and must therefore have a high temperature tolerance. Usually, however, the machines are kept in climate-controlled measuring labs where they are protected against vibrations and major temperature fluctuations.

The causes of temperature fluctuation vary enormously and can be quite difficult to identify. People are one major cause. While employees stopping by on their way to lunch might improve the measuring team's mood, it does not improve the measurement results. From a technical viewpoint, a human being is a biological reactor with an operating temperature of 37 degrees Celsius. At an ambient temperature above 16 degrees Celsius, the typical person has a thermal output of 120 watts – the equivalent of two mid-sized incandescent bulbs. The ambient temperature has no effect on this value.

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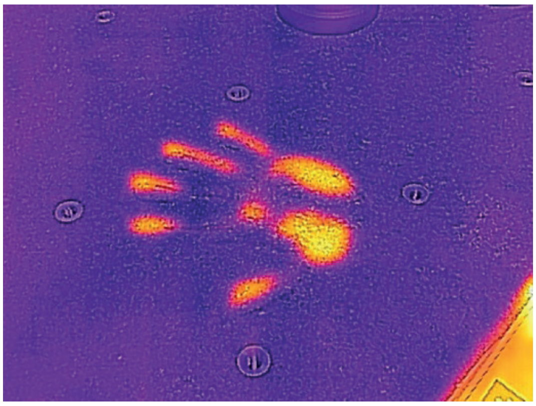

Just one wrong move can mean worthless results

It is sad but true: a brief visit from a colleague or inadvertently putting your hand in the wrong place can have unintended consequences. If a measuring technician places their hand on the CMM's granite plate (even for just a few seconds) when adjusting the workpiece or the stylus, then the temperature at this spot increases for some time, demonstrated by thermal cameras showing a distinct handprint. The closer the operator's hand was to the workpiece, the greater the measuring error. Yet there is no end to the number of other culprits in the measuring lab that can affect the temperature: computers, sunlight, lighting, ventilation, component temperature before the measurement and much more. In the production area, the ambient temperature usually deviates from the stipulated reference temperature. The fluctuations occur when, during the night, heat sources like the heating, machines and lighting are turned off and fewer people are on the shop floor. During the day, the space heats up along with the measuring machine. It should be noted that, because of its small dimensions, the tape scales are more quickly affected by the temperature change than the massive guide rails. Moreover, sometimes workpieces are measured with a post-machining temperature greater than the ambient temperature. The measurement uncertainty is significantly greater if no temperature compensation is performed in these instances because either the measuring machine does not have this feature or the operator is not aware of the effects.

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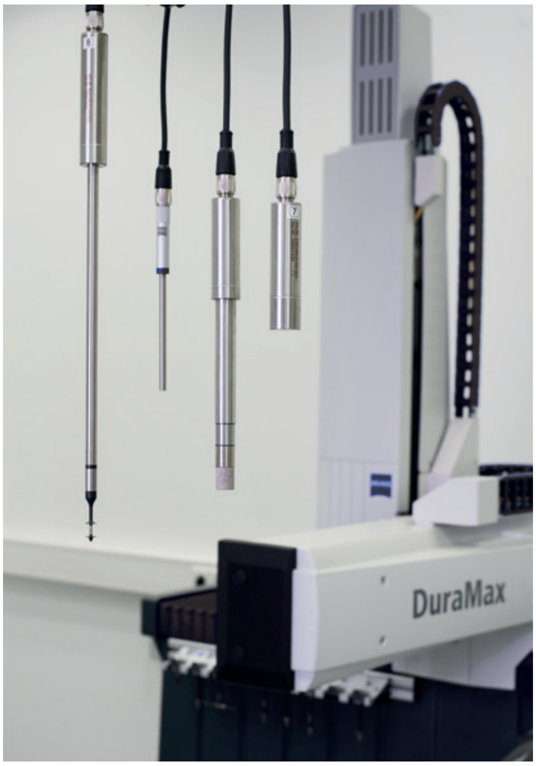

Don't trust your gut

While all this is obvious, there is often a tendency to underestimate the impact of temperature on the accuracy of the CMM results. This might be due to the fact that we do not notice the difference of one-tenth of a degree Celsius ourselves because our skin and metabolism are not that sensitive. Thus we draw the erroneous conclusion that these minimal changes also do not play a role when measuring workpieces on a CMM. In fact, that opposite is true. Depending on the material and shape, slight temperature changes can cause the test piece to expand or contract considerably, quickly leading to exceeded tolerance limits and measurement values that do not reflect dimensions at the defined temperature. If the temperature changes during the measurement run, then incorrect values are used to correct the measurement.

Manufacturers specify the errors for probing and length measurements in accordance with DIN EN ISO 10360. The values refer to characteristics defined on calibrated standards with particular styli. The manufacturer stipulates a particular temperature range as well as maximum temperature gradients per hour or day (e.g. maximum of 0.5 K per hour and maximum of 1 K per day) and spatial temperature gradients (e.g. maximum of 0.5 K per meter). Often, many users only pay attention to the absolute temperature limits and neglect these gradients.

The temperature gradients in particular are decisive for the expansion behavior of the measuring machine. As long as you are familiar with this behavior, then each change can be accounted for in the measurement with the assistance of computer software. However, if these gradients are not observed, then the geometry of the measuring machine and its components changes in ways that cannot be accommodated, such as the guideway elements or tape scales.

It is especially important to select the right materials. That is why the floating ZERODUR tape scales have an extremely low expansion coefficient, making them almost immune to temperature fluctuations.

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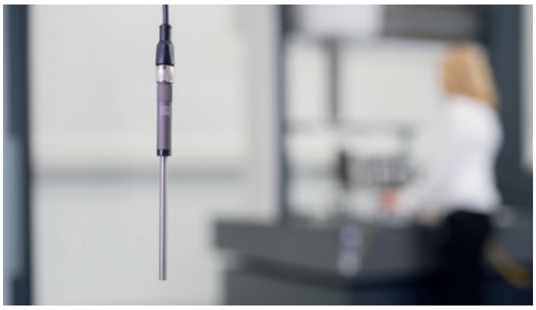

Tips for better measurements

Rather than leaving accurate measurement results to chance, users should observe the following six tips:

- ✔ Ensure ambient temperatures remain consistent.
- ✔ Avoid subjecting the CMM to strong air currents.
- ✔ Make sure there are no heat sources in the immediate vicinity.
- ✔ Check that the artifacts are acclimatized sufficiently prior to the measurement.
- ✔ Use the temperature compensation feature, if available.
- ✔ Measure the temperature in the area where you store your components.

Tip 1 requires a climate-controlled measuring lab, which most companies have. The quality of the measuring lab determines how much effort is required to maintain a stable temperature. In Germany, VDI/VDE directive 2627 specifies four classes of measuring lab. In the highest class, workpieces are measured with micrometer and submicrometer precision. A sophisticated climate-control system, locks and preliminary airlocks are required to guarantee a stable ambient temperature of 20 degree Celsius plus/minus 0.2 Kelvin throughout the precision measuring lab at all times. These labs use a mixture of ambient and fresh air. Heat, such as from the controller cabinets or illumination systems, is removed directly at the source. A code system regulates access to these measuring labs so that only a specified number of employees can enter.

Keeping a constant eye on the temperature

Even with the best climate control system, you should not rely on this alone. It is far more advisable to install a temperature monitoring system such as TEMPAR from ZEISS. The networked sensors capture the lab temperature at different locations while software records the data and calculates the temporal and spatial temperature gradients. If limits are exceeded, the system sounds the alarm.

Looking more closely at temperature compensation is also worthwhile. Nearly all workpieces are subject to temperature influences which must be eliminated as much as possible. The length error DL caused by the temperature is determined by the expansion coefficients of the materials and the deviations from the reference temperature of 20 degrees Celsius:

$$\Delta L = L\,(\alpha_W * \Delta t_W - \alpha_S * \Delta t_S)$$

L	Nominal length
α	Linear coefficient of expansion
Δt	Deviation from the reference temperature, $\Delta t = t - 20°C$
W	Index for workpiece
S	Index for scale

The effect of 0.1°C

When considering a single workpiece, the temperature fluctuation change in length can be simplified using the following formula:

$$\Delta L = L * \alpha * \Delta t$$

Example calculation:

Nominal length L: 500 mm aluminum workpiece
Temperature change Δt: 0.1 K
Coefficient of expansion of aluminum: 23.8 µm/m*k

23.8 µm/mK * 0.1K * 0.5m = 1.19µm

Even a "tiny" temperature deviation of 0.1 °C causes a deviation of 1.2 µm for aluminum materials.

The length errors caused by temperature should be corrected if required by the tolerances and the temperatures of both the workpiece and the tape scale of the measuring machine are known. You then subtract the deviation calculated using this equation from the measured length.

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Temperature compensation – but how?

This compensation only works if several preconditions are met. The temperature should be the same within the workpiece so that there are no local deformations. The temperature on the workpiece and in the lab should be as uniform and consistent as possible, including between the floor and the ceiling. It should also be possible to determine this with sufficient accuracy. The stylus systems should be qualified under the same temperature conditions as the measurements. Otherwise, requalification is required. Be careful when measuring materials with different expansion coefficients within the workpiece or between the workpiece and the fixturing system. The temperature should always be measured at thick and never at thin areas on the workpiece. When determining linear expansion, the compensation becomes more difficult with more complex workpiece geometries. In any event, the measuring technician must perform temperature compensation with great care as the risk of an incorrect calculation is extremely high. The manufacturer's requirements should always be observed. Avoid relying on compensation alone. Instead, it is always advisable to first do everything possible to keep the temperature in the measuring lab and on the workpiece as uniform as possible.

Conclusion

The temperature has a considerable impact on the measuring accuracy. However, temperature influences in the measuring lab can only be reduced, rather than eliminated completely. There are tools for keeping the temperature constant so that measuring technicians can concentrate on the measurement itself.

Linear expansion coefficients

When performing a length measurement, the thermal expansion that affects all components when the temperature increases must be observed. This table gives you an overview of the expansion coefficients for different materials. Alloys and composite materials have special coefficients. You can obtain these from the supplier. Since the measuring temperature is included in the absolute expansion, the measurement should always be performed using a qualified thermometer with a known measurement uncertainty.

Material	[µm / m K]	Material	[µm / m K]
aluminium	23.8	copper	16.8
aluminium oxide	7.8 to 8.3	magnesium	26
concrete	12	marble	ca. 11
lead	29	brass	18
bronze	17,5	nickel silver	18
chrome	6,6	nickel	12.8
iron	12,1	Ruby/Sapphire	5.4
soft steel	11	silver	19.7
glass	8 to 9	silicon nitride	3.2
gold	14.3	Steel (stainless)	16
granite	3 to 8	titanium	9,2
graphite	7.9	Zerodur	0.02
cast iron	11 to 12	tin	27
carbide shank	ca. 5.1	zinc	27
CFK Carbon fiber	- 0.4	zirconium oxide	9 to10.5

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