CMM Thermal Gradients

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Purpose

This article describes some of the problems when thermal gradients exist on a CMM. There are different kinds of thermal gradients and the focus of this article is on differences in temperature between the axis of a CMM and not thermal gradients in material such as the granite base.

The usual reason for differences in axis temperature is a combination of the room size the CMM is installed in, the proximity to outside walls, and the amount of airflow around the machine. A poor setup is to have a CMM installed in a room not much bigger than the CMM itself with no airflow and next to an outside wall. Machines installed in rooms where it is necessary to have a ceiling pocket can be a poor setup but this can work if steps are taken to minimize thermal gradients.

Thermal gradients between the axis of a CMM can be tolerable if temperature compensation is used as this can reduce the relative error between the machine axis.

Thermal Gradient Example

Illustration 1 shows an example of a CMM installation that is subject to thermal gradients. The example is a mock-up of common problems seen over the years for CMM installations where the pendulum swings too far in the direction of practical instead of ideal.

In this mock-up the axis temperatures are as follows:

Axis	*Temperature °C*	*Comments*
X	22	X axis roughy 60% of distance from floor to ceiling. X temperature is a combination of two sensors from left and right of axis.
Y	19	Y axis roughly 10% of distance from floor to ceiling. Y axis close to outside wall.
Z	23	Z temperature is a combination of two sensors top and bottom of the axis. The upper sensor will show a much higher temperature than the lower and will change depending on where the machine happens to rest.

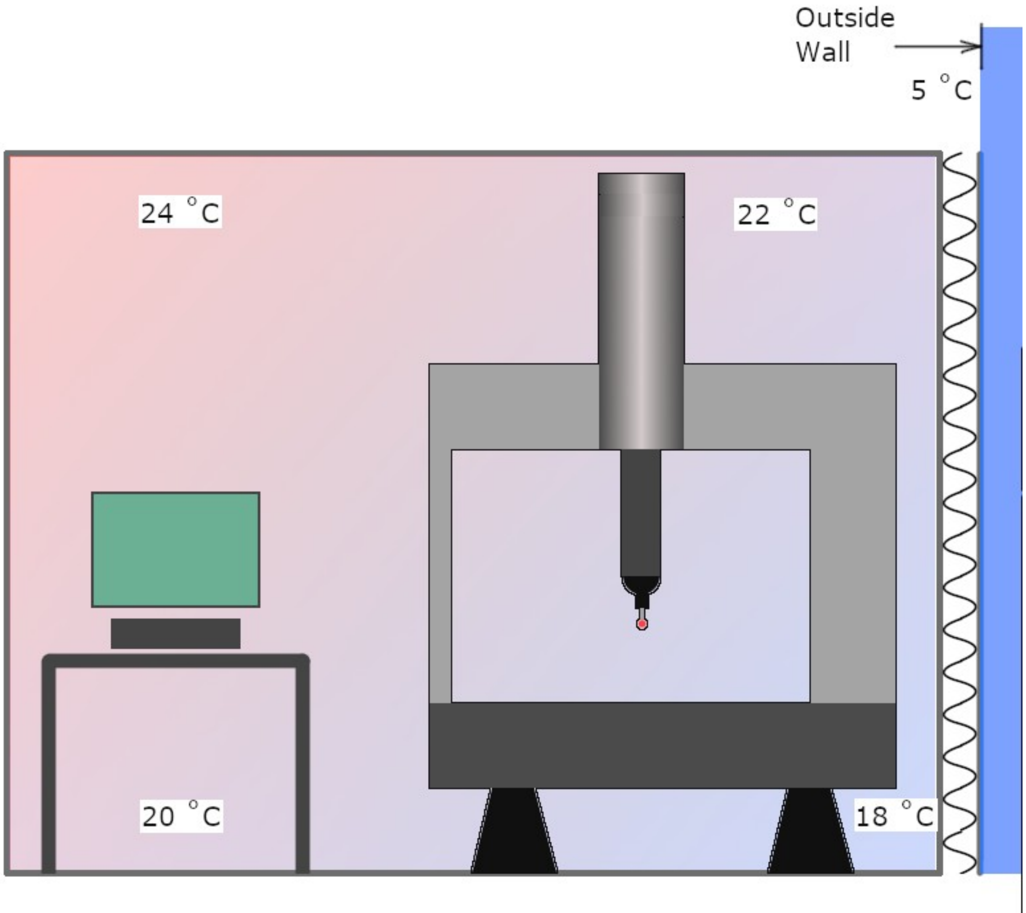

Illustration 1: CMM installation subject to thermal gradients.

Expected Measurement Error

When setup in an environment as shown in illustration 1 with the axis temperatures as described in the section *Thermal Gradient Example* the following errors are expected from the measurement of a 1 meter length with an expansion of 0 um/m/°C without temperature compensation:

Axis	*Measured Length*	*Comments*
X	999.980	X axis is 2°C above the reference temperature. Axis expansion is 10 um/m/°C.
Y	1000.010	X axis is 1°C below the reference temperature. Axis expansion is 10 um/m/°C.
Z	999.970	Z axis is 3°C above the reference temperature. Axis expansion is 10 um/m/°C.

The machine expansion coefficients for each axis is assumed to be 10 um/m/°C which is common for machines using typical tape scales that are secured at only one end.

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The expected measurement errors listed in the previous table assume that temperature compensation is not used. Older or base-model CMM's usually do not have the ability to report the axis temperatures which makes temperature compensation impractical for day-to-day use. Newer models of CMM's often have temperature sensors mounted along the axis but that does not automatically mean temperature compensation is used particularly when the function is overly-complicated in the inspection software.

As of the writing of this article the author is not aware of any company that uses temperature compensation for day-to-day measurement of parts.

Requirements From 10360-2

The following is an excerpt from ASME B89.4.10360-2:2008:

> *The ambient temperature specifications apply to the envelope of the CMM; this is the volume of space occupied by the entire CMM structure under the full extent of travel of all axes, starting 25 mm (one inch) above the floor The specifications apply to the room with the CMM present and under normal power requirements hence attention should be paid to the power dissipation of the CMM and the thermal environment provided accordingly.*

For practical reasons temperature measurement of the CMM's volume envelope is usually not done. It would require setting up minimum of eight temperature sensors at the different corners of the machine's volume and monitoring over a period of 24 hrs.

When a new installation of a CMM is performed, particularly considering the strict acceptance requirements, this kind of elaborate structure to monitor envelope temperatures is a good idea.

Calibration Impact

The impact from the temperature gradient when testing the measurement performance of the CMM depends on the availability of temperature compensation. Most calibration providers know to use temperature compensation when testing a CMM (even machines without dedicated axis temperature sensors) but novice users running interim checks of the machine usually do not take this into account. The measured values can be alarming as a result.

With the axis temperatures described in the previous *Thermal Gradient Example* section the best results that could be achieved from a simple ball-bar length repeatability check would be 0.040 mm with a ball-bar nominal length of 1000 mm.

When using a calibrated ball-bar for the interim tests the number of measurements along a specific axis will bias the results. If the mean length of the ball-bar is considered this bias will be an additional error source.

In this authors opinion a ball-bar length repeatability test of a CMM is meaningless if temperature gradients exist in the machine and temperature compensation is not used. All CMM software has the ability to perform temperature compensation in some form and this should be used. Machines without active temperature sensors require an external thermometer.

Ceiling Pockets

On occasion a CMM will be installed in a room that requires modification of the ceiling to fit the machine. This usually makes the problem of thermal gradients even worse because warm air will builds up inside the area of the ceiling pocket. If this is the case then extra steps need to be taken in order to prevent a buildup of warm air inside the ceiling pocket.

Measurement Uncertainty

When estimating the measurement uncertainty from a CMM that has thermal gradients the impact of the gradient must be included as it is easily a large source of error particularly if temperature compensation is not used during normal measurement procedures.

When the thermal gradients are influenced by the outside temperature as shown in illustration 1 the size of the gradients will change seasonally. This should be considered when developing a measurement uncertainty budget.

The best way to determine the range of the gradients over the course of a year is to perform temperature measurements of the axis monthly and consolidate annually.

Reducing Thermal Gradients

Thermal gradients can be reduced by one or more different methods:

- Large volume room. Lots of ceiling height above the CMM is always best. Ceiling pockets are the worst.
- Circulation fans. There should always be air-flow around the CMM.

The solution is actually not that difficult to implement. Having fans running around the machine will increase the ambient noise level which is not ideal for the operator. Installing dedicated circulation vents around the machine with a blower in an adjacent room is better overall but involves some planning when setting up the room.

Revision History

Revision	*Date*	*Reason*
1	Nov 29, 2022	Initial Release
2	Dec 4, 2022	Expected measurement deviation sign wrong.