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Thermal correction - workpiece expansion

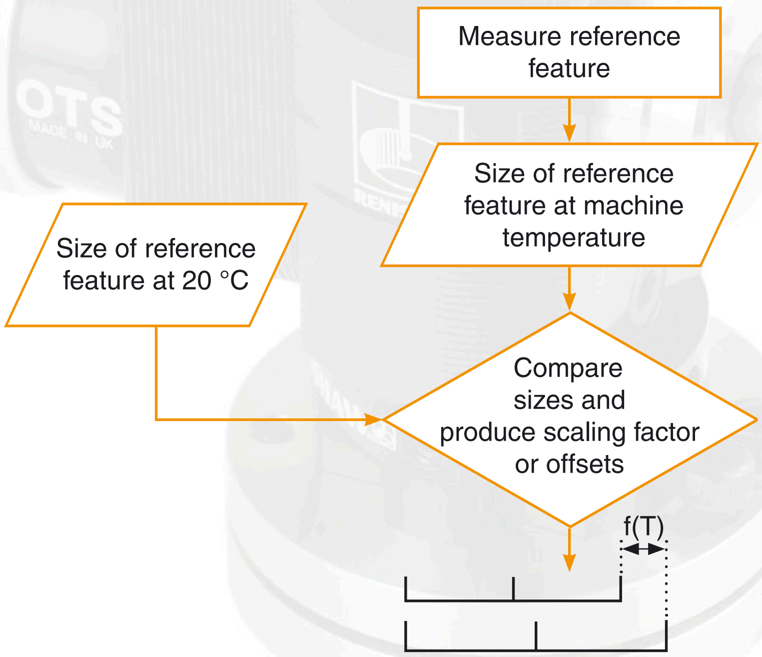
Expansion and contraction caused by thermal effects can occur in both machine tool components and workpieces. Techniques for compensating for these thermal effects can be applied to address machine drift and workpiece expansion, although the most suitable approach for any manufacturing situation will depend on a variety of factors. These would include machine design, operating environment, workpiece properties and other manufacturing processes used prior to and after each machining operation.

This Productive Process Pattern™ (AP306) is one of two Patterns describing thermal correction. It addresses location and dimension problems arising from thermal expansion of workpieces. For further information about thermal correction, reference should also be made to *AP303, Thermal correction - machine drift*.

Problem

Workpieces can be subject to expansion and contraction owing to thermal effects. Variation in temperature of the machining environment or heat generated in the part during machining operations can affect the size and location of parts and features whilst they are on a machine. Temperature sensors built into the machine can report conditions to the machine control so that it can apply thermal compensation algorithms. However, workpieces or their individual features cannot report their own temperature values to the machine control and their thermal expansion properties are not usually accurately modelled.

Machines are unable to infer the change in components' dimensions or feature positions owing to thermal expansion, therefore variation in the temperature of a workpiece and its resultant thermal expansion can cause systematic errors and process variation. Thermal effects may cause measurement uncertainty to be excessive compared to the tolerances required on a part, and can be responsible for position and dimension errors in measurement and machining.



Solution

Use a workpiece inspection probe to measure the size of a reference feature in the machine environment and compare it with the known size of that feature at 20 ºC. Produce and apply a scaling factor or offsets for subsequent machining operations and proceed based on parameters corrected for thermal effects.

This method makes the following assumptions:

- The dimension of the feature or part measured at the actual machine temperature is accurately known at 20 ºC
- The scaling factor algorithm is applicable to all features whose machining will be affected by the updated parameters
- The co-efficient of thermal expansion (CTE) of the reference feature is identical or close to that of the part being machined
- Thermal expansion is unconstrained on the parts

A known feature on a workpiece which has been produced by a prior operation may be used to take a reference measurement at actual machine temperature for comparison with its known size at 20 ºC. Alternatively, an 'artefact' (a calibrated or known 'golden' part) with features and thermal expansion behaviour comparable with those of the workpiece, may be measured to identify thermal expansion then parameters adjusted accordingly.

When designing an artefact for comparative measurement, the dimensions and thermal properties of the workpieces for which thermal correction will be applied should be considered. Similar materials, CTE and dimensions are desirable. The use of an artefact can enable the machining process to be traceable to known standards if the artefact is regularly calibrated (ideally using a CMM). The use of coolant washes over artefacts and workpieces can help to keep both parts at similar temperatures so they are subject to similar expansion effects.

Workpiece expansion can cause location and dimension errors. The type of thermal correction required to compensate for workpiece expansion depends on the type of error which needs to be addressed.

1. Where a part or datum feature location has shifted because of thermal effects, a work co-ordinate system (WCS) shift can be applied in order to ensure subsequent machining takes place in the correct location. In some situations, it may be more suitable to use probing results and logic statements to update a parametric machining program in order to affect the path of machining moves using scaling factors.

2. Where a part or feature has changed dimension because of thermal effects, probing results and logic statements may be used in this situation to update a parametric machining program in order to affect the path of machining using scaling factors. It is also possible to apply a cutter parameter update to compensate for thermal drift of feature dimensions.

The importance of considering thermal effects for features of various sizes and tolerances is illustrated in figure 1.

% of tolerance consumed by thermal growth where temperature varies by ±5 °C for steel
(with CTE value of 11 µm / m / °C)

Feature size	Tolerance			
	±5 µm	±25 µm	±50 µm	±100 µm
10 mm	11%	2%	1%	1%
25 mm	28%	6%	3%	1%
50 mm	55%	11%	6%	3%
100 mm	110%	22%	11%	6%
250 mm	275%	55%	28%	14%
500 mm	550%	110%	55%	28%
1000 mm	1100%	220%	110%	55%
2500 mm	2750%	550%	275%	138%
5000 mm	5500%	1100%	550%	275%
Significance of thermal growth				
0% - 10%	Insignificant			
11% - 30%	Significant			
> 30%	Dominant			

Figure 1: significance of thermal growth

Benefits

- Reduces the need for thermal control on the machine
- Increases the range of environmental conditions within which the machine can reliably operate
- Reduces variation in machined parts caused by thermal effects

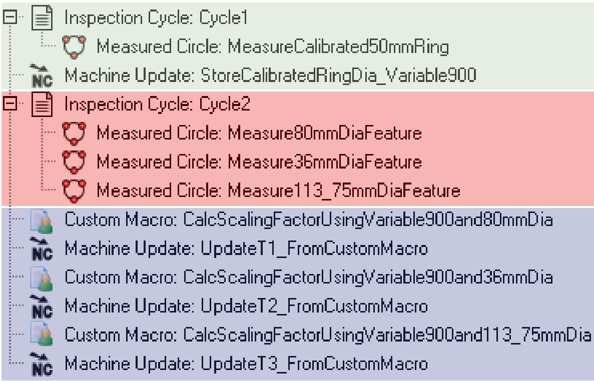
Case study

Renishaw's own RAMTIC (Renishaw's Automated Milling Turning and Inspection Centre) machines utilise artefacts to compensate for thermal errors and provide a link to a known standard of accuracy. The artefact is periodically calibrated on a co-ordinate measuring machine (CMM) so that on-machine measurements are traceable to a known standard.

Example: applying a scaling factor based on the size of a feature measured at machine temperature

A measuring cycle is performed and a tool update applied for each tool used in the machining process.

Sample Productivity+™ probe software program



A feature of known diameter at 20 °C and with the same expansion co-efficient as the component to be machined, is placed in the machine envelope. The diameter is measured and stored to a variable (#900).

An inspection cycle measures the diameter of three critical features on the component.

A custom macro compares the measured size of the calibrated ring against known size at 20 °C to calculate the scaling factor. This result is then adjusted based on expected deviation of the first critical feature, and a (subsequent) tool update applied to remove that expected deviation.
These steps are repeated for each critical feature and the tool used to produce it.

Sample Inspection Plus software program

N10	
T1 M6	
G54 X0. Y0.	
G43 H1 Z100.	
G65 P9810 Z-10. F3000	
G65 P9814 D50.003	A feature of known diameter (50.003) at 20 °C and with the same expansion co-efficient as the component to be machined is placed in the machine envelope and measured
#900 = #143	Store deviation from calibrated size
	(move to feature 1)
G65 P9814 D80.000	Measure part feature - 80 mm diameter
#143 = #143 - [#900 × 1.6]	Calculate expected deviation at 20 °C by applying scaling factor (1.6)*
G65 P9732 T1.	Update tool offset 1 to remove expected deviation
	(move to feature 2)
G65 P9814 D36.000	Measure part feature - 36 mm diameter
#143 = #143 - [#900 × 0.72]	Calculate expected deviation at 20 °C by applying scaling factor (0.72)*
G65 P9732 T2.	Update tool offset 2 to remove expected deviation
	(move to feature 3)
G65 P9814 D113.75	Measure part feature - 113.75 mm diameter
#143 = #143 - [#900 × 2.275]	Calculate expected deviation at 20 °C by applying scaling factor (2.275)*
G65 P9732 T3.	Update tool offset 3 to remove expected deviation
G91	
G28 Z0.	
G90	
N20	
	Continue machining

* The scaling factor is derived from comparison between known diameter (at 20 °C) and measured size of the reference feature. Assuming linear expansion, this deviation is scaled up or down for other features on the part.

SAMPLE PRODUCTIVITY+™ PROGRAMS ASSUME THE USE OF ACTIVE EDITOR PRO 1.70.20
SAMPLE INSPECTION PLUS PROGRAMS ASSUME USE WITH FANUC TYPE CONTROLS

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Products include:

- **Dental CAD/CAM scanning and milling systems.**
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- **Probe systems and software for job set-up, tool setting and inspection on CNC machine tools.**
- **Raman spectroscopy systems for non-destructive material analysis.**
- **Sensor systems and software for measurement on CMMs (co-ordinate measuring machines).**
- **Styli for CMM and machine tool probe applications.**

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