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Thermal correction - machine drift

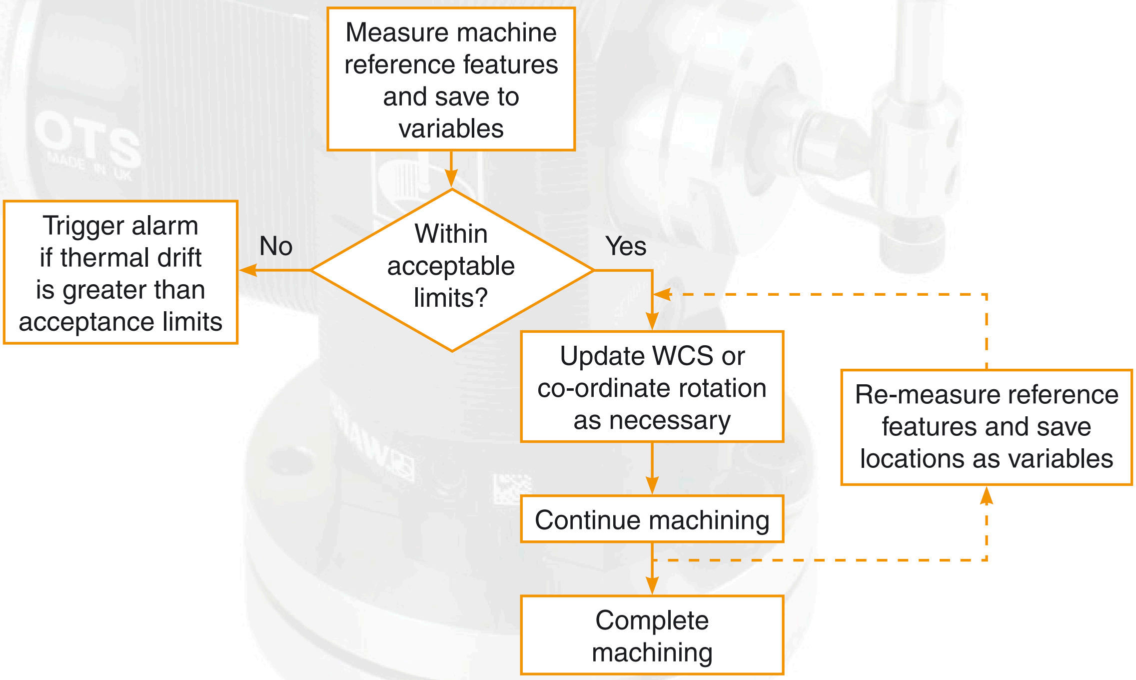
Expansion and contraction caused by thermal effects can occur in both machine tool components and workpieces. Techniques for compensating for these thermal effects can be applied to address machine drift and workpiece expansion, although the most suitable approach for any manufacturing situation will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

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

Problem

Variation in temperature of the machining environment causes expansion and contraction of machine components owing to thermal effects. Temperature variation can be caused by ambient temperature changes, self-generated heat in machine ballscrews and spindles, local heating affects owing to friction, and heat soak from major power sources.

Temperature gradients can cause unpredictable changes in machine geometry owing to the different thermal expansion properties of the various materials and masses used in machine tool construction, and the constrained growth which occurs when machine components expand. As parts of a machine move, critical alignments and machine geometries are affected and may introduce systematic errors and process variation. Thermal distortion on machines constantly changes inter-axis relationships and can result in rotary axes being mis-aligned or positioned incorrectly with respect to linear axes. Such machine distortions cause variation in the location and size of the parts or features a machine produces.



Solution

Temperature sensors built into the machine can report conditions to the machine control so that it can apply thermal compensation algorithms. However, such compensations are based on predictions of how the machine will be affected by thermal distortion. Although the compensations can be used to improve machine performance, they cannot provide responses to precise machine behaviour, localised effects, and complex inter-relationships. It is therefore desirable to measure and account for the actual machine behaviour.

Methods used to assess and account for actual machine thermal drift can be used for two key tasks:

- Machine setting tasks (before and during machining cycles)
- Machine acceptance tests to check for thermal stability

Machine setting tasks

Using a toolsetting probe

Where applicable, an on-machine toolsetter can be used to track movement in a machine's Z-axis caused by thermal effects. Comparisons between Z length measurements taken over time can be used to determine the extent to which the machine has experienced drift in that axis. The measurements allow for updates to be applied to relevant offsets or parameters in order to maintain a stable machining process. (For information on using a tool setting probe for tool condition monitoring, see *AP304, Tool condition monitoring*.)

Using a workpiece inspection probe

The use of a workpiece inspection probe is an alternative way to perform on-machine measurement checks at the setting stage and during production. Measurements from probing can be used to re-establish key geometric relationships which may be adversely affected by thermal drift. The types of checks required vary with machine type but they will involve locating a critical machine reference feature using an inspection probe then tracking the position of that feature in order to detect machine drift.

It is possible to mount multiple artefacts, such as calibration spheres, in critical working areas of a machine in order to provide easy-to-probe features which drift with the machine. These can indicate the extent to which thermal effects are present. Geometric errors can be calculated and accounted for using local part datums or updated co-ordinate rotations.

Thermal drift errors have three main effects, which need to be addressed with methods appropriate to the type of effect:

1. Drift in spindle position means the machine co-ordinate system (MCS) cannot be relied upon to define part location - any uncorrected machining would take place in the wrong position on a part, producing features in the wrong position. Use of a work co-ordinate system (WCS) and, if necessary, co-ordinate rotation can correct for drift in spindle position.
2. Thermal growth can cause the machine and part to grow - machined features could be measured and produced at the wrong size. Use of artefacts (calibrated 'golden parts') can account for scaling errors in order to produce features which will be the correct size at a standard reference temperature (see Pattern *AP306, Thermal correction - workpiece expansion*).
3. Thermal growth can cause the machine and part to distort - machined features could be produced at the wrong angle and position. Changes in alignment between rotary and linear axes can be compensated for by using local part datums or updated co-ordinate rotations.

When devising a thermal correction strategy to account for machine drift, the following considerations are important:

- Key geometric relationships
- Sources of geometric variation
- Machine setting methods
- Workpiece properties and thermal behaviour
- Required calibration regimes

Machine acceptance tests to check for thermal stability

Tests to establish machine thermal drift characteristics can be included in reference specification tests as part of machine assessment prior to delivery or handover. The machine is tested to ensure it satisfies thermal stability acceptance criteria determined by the user in order to ensure drift will be within acceptable limits for the machining application, or for in-process control to be able to correct for the drift. Such tests typically involve warm-up and cool-down cycles combined with frequent measurement of machine reference features using a workpiece inspection probe.

Benefits

- Increases the range of environmental conditions within which the machine can reliably operate
- Reduces variation in machined parts caused by thermal effects
- Reduces the need for thermal control on the machine
- Machine acceptance tests ensure production machines meet specifications so that the extent of inherent variation is known and can be compensated

Case study

Renishaw's own RAMTIC (Renishaw's Automated Milling Turning and Inspection Centre) machines determine critical indexer positions at the start of a machining cycle. At this time, reference points are taken and stored. After rough machining has been completed, these reference points are re-measured. Any deviation from stored values is used to 'shift' work coordinate systems ensuring accurate part geometry.

Example: A conventional 3-axis machining centre comprises 3 orthogonal stacked axes. The machine bed typically moves in one or two directions whilst the spindle moves in the others. The spindle may be vertical or horizontal.

The key geometric relationship is the spindle position relative to datum features on the machine bed or workpiece fixture.

Sources of geometric variation include:

- Thermal growth in X, Y and Z axes
- Spindle motor heating
- Differential thermal growth of the machine tool probe and tools

Machine setting methods involve measurement of datum feature(s) in X, Y and Z, and periodic re-affirmation of the feature positions

Sample Productivity+™ probe software program

Inspection Cycle: Cycle1 Measured Circle: MeasureReferenceFeature1	Reference features 1 and 2 are a known distance away from each other in X and Y. Measure the first reference feature
Machine Update: UpdateWCS_XY	Update the WCS using the measured feature data
Inspection Cycle: Cycle2 Measured Circle: MeasureReferenceFeature2	Measure the second reference feature
Machine Update: StoreRing2XPosition_Variable900 Machine Update: StoreRing2YPosition_Variable901	Store the X position error to a variable (e.g. #900) Store the Y position error to a variable (e.g. #901)
G-Code Block: MachiningUsing_Variables900_and_901	Machine using nominal X and Y positions plus associated errors (stored in #900 and #901)

Sample Inspection Plus software program

N10	
T1 M6	
G54 X#902 Y#903	Move to stored coordinates of reference feature 1
G43 H1 Z100.	
G65 P9810 Z-10. F3000	
G65 P9814 D10.000 S1	Measure reference feature; update G54
G65 P9810 X#904 Y#905	Move to stored coordinates of reference feature 2
G65 P9814 D10.000	Measure reference feature 2
#900 = #140	Store X position error (returned as #140, to #900)
#901 = #141	Store Y position error (returned as #141, to #901)
	Machining
G54 G90 X0 Y0	
G0 X[100. + #900] Y[50. + #901]	Move to nominal X and Y positions plus associated errors (#900 and #901)

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Renishaw is an established world leader in engineering technologies, with a strong history of innovation in product development and manufacturing. Since its formation in 1973, the company has supplied leading-edge products that increase process productivity, improve product quality and deliver cost-effective automation solutions.

A worldwide network of subsidiary companies and distributors provides exceptional service and support for its customers.

Products include:

- **Dental CAD/CAM scanning and milling systems.**
- **Encoder systems for high accuracy linear, angle and rotary position feedback.**
- **Laser and ballbar systems for performance measurement and calibration of machines.**
- **Medical devices for neurosurgical applications.**
- **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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