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IMPROVING MACHINING ACCURACY ON CNC MACHINE TOOLS THROUGH CAM-BASED THERMAL DEFORMATION COMPENSATION

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Abstract

Thermal deformation causes a large share of the dimensional error of CNC machine tools, often cited as 40–70%. This paper proposes compensating it at the CAM stage: a thermal model predicts the spindle's growth, and the CAM post-processor writes the correction into the NC program as a work-offset update. A worked example shows a 23.8 μm spindle elongation after 30 minutes, corrected by a G54 Z-offset change of +0.0238 mm.

Keywords: thermal error; CNC machine tool; CAM post-processor; spindle elongation; compensation

1. Introduction

Heat from the spindle bearings, motor and feed drives expands the machine structure while it runs, so the tool-to-workpiece position drifts over time. Unlike geometric errors, this drift changes with the duty cycle and cannot be calibrated once [1, 2].

Most compensation today runs inside the CNC controller, tied to one vendor and often sold as a paid option. Applying the correction in the CAM post-processor makes it controller-independent and usable on older machines.

Aim: to increase machining accuracy by compensating thermal deformation of the spindle through the CAM system.

2. Method

The spindle assembly is treated as one thermal mass heated by power P and cooled by convection. Its temperature rise is:

$$\Delta T(t) = \frac{P}{hA}(1 - e^{-t/\tau}), \qquad \tau = \frac{m\,c}{hA} \quad (1)$$

where m is the mass, c the specific heat, h the heat-transfer coefficient, A the cooling surface and τ the thermal time constant. The resulting axial elongation of a spindle of length L is:

$$\delta L(t) = \alpha\, L\, \Delta T(t) \quad (2)$$

The spindle grows toward the table, so the post-processor raises the Z work offset by the predicted elongation at the time t_i the block will run:

$$Z_{offset}(t_i) = Z_{offset,\,0} + \delta L(t_i) \quad (3)$$

3. Calculation example

Input data (representative values for a vertical machining centre) are given in Table 1.

Table 1. Input data

Parameter	Value
Spindle assembly mass, m	85 kg
Specific heat (steel), c	460 J/(kg·K)
Heat-transfer coefficient, h	15 W/(m²·K)
Cooling surface, A	1.2 m²
Heat input at 8000 min⁻¹, P	220 W
Spindle thermal length, L	300 mm
Expansion coefficient, α	11.5×10⁻⁶ 1/K
Nominal G54 Z offset	−412.4000 mm

Step 1 — heat-loss factor: $hA = 15 \times 1.2 = 18.0$ W/K.

Step 2 — steady-state temperature rise: $\Delta T_{ss} = 220 / 18.0 = 12.22$ K.

Step 3 — time constant: $\tau = (85 \times 460) / 18.0 = 2172$ s = 36.2 min.

Step 4 — temperature rise after 30 min (1800 s): $\Delta T = 12.22 \times (1 - e^{-1800/2172}) = 12.22 \times (1 - 0.437) = 6.89$ K.

Step 5 — spindle elongation: $\delta L = 11.5\times10^{-6} \times 300 \times 6.89 = 0.0238$ mm = **23.8 µm**.

Step 6 — corrected offset: $Z = -412.4000 + 0.0238 =$ **−412.3762 mm**, written by the post-processor as:

(THERMAL COMP T=30 MIN DZ=+0.0238)
G10 L2 P1 Z-412.3762

Without this correction a 30 mm deep pocket would be 23.8 µm too deep, outside the IT7 tolerance of 21 µm [4]. At steady state the uncorrected error would reach 42.2 µm.

4. Conclusions

1. The spindle in the example grows 23.8 µm in 30 minutes and up to 42.2 µm at steady state, enough to break IT7 tolerances.

2. The thermal growth can be predicted from basic machine data and written into the NC program as G10 offset updates.

3. CAM-based compensation needs no controller option; it should be validated on a real machine per ISO 230-3 [3].

References

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