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Optimising temperature sensor placement for machine tool thermal error compensation

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Abstract

In this article, results of thermal error assessments are evaluated from a range of modern machine tools operating with active thermal compensation. The standard models assume a linear relationship between temperature and displacement and implementations address only a limited subset of error sources. However, significant residual errors were found on the analysed machines. The aim of this work is to improve the accuracy and increase the scope of compensated errors, without introducing onerous complexity, by using optimised linear correlation models applied to existing controllers.

1 Introduction

Most modern Computer Numerical Controllers (CNCs) have functionality to compensate for geometric errors. This is recognised as a cost-effective way of improving the accuracy of machine tools when compared to mechanical adjustment. Similarly, numerical compensation of thermally induced errors can also be the most effective solution compared to design effort, use of advanced materials or cooling systems. As a result, thermal modelling, error measurement and compensation have been the focus of significant research using a variety of technologies and methodologies [1]. However, the prevalent model used in industry is a linear relationship between temperature and displacement, largely because of the simplicity of implementation. This paper reviews results from thermal assessments made on several recently installed machines that have nominally been “thermally compensated” to determine which error sources are not addressed as well as the effectiveness of the active compensation. The potential for improvement by optimal placement of a single temperature sensor using correlation searches on thermal imaging and FEA data is then shown.

2 Thermal error assessment review

A range of modern, commercial machines in different factories were investigated. Each machine had thermal compensation as standard from the manufacturer. The table below summarises which errors were found to be compensated in a selection of the machines. The typical effectiveness of the active compensation for step heating and cooling tests (ISO 230-3:2007) was 50%. In most cases, errors associated with the axes (linear scale feedback in nearly all cases) had position dependent and independent thermal error up to 40µm, and environmental effects were not compensated.

Key: S is spindle heating result, subscripts *m* & *c* indicate milling and C axis (main) spindles respectively, A and E are axis and environmental results respectively.

Approx. Size and type	Comp	No comp
Large 5ax horizontal mill-turn	Sm	Sc, AX, AY, AZ, E
Medium 5axis vertical mill-turn	Sm, Sc	AX, AY, AZ, E
Small C-Frame 3axis milling	Sm	AX, AY, AZ, E
Large vertical lathe	Sc	AX, AY, AZ, E

3 Correlation search using thermal imaging

Thermography can be an efficient method of temperature measurement of the entire influencing structure. For the Medium 5-axis machine, a thermal error of 150 µm, reduced to 75 µm with standard compensation, was improved to 20 µm using unconstrained nonlinear optimisation with the image pixel data. In some cases, optimal sensor location can be difficult determine. On the small 3-axis machine the intuitive heat sources of the nut and bearings did not correlate and neither did the structure near the reader head or scale. Searching the thermal imaging sequence identified the sensor location on the saddle close to the end of the guideway. The results are shown in Figure 1.

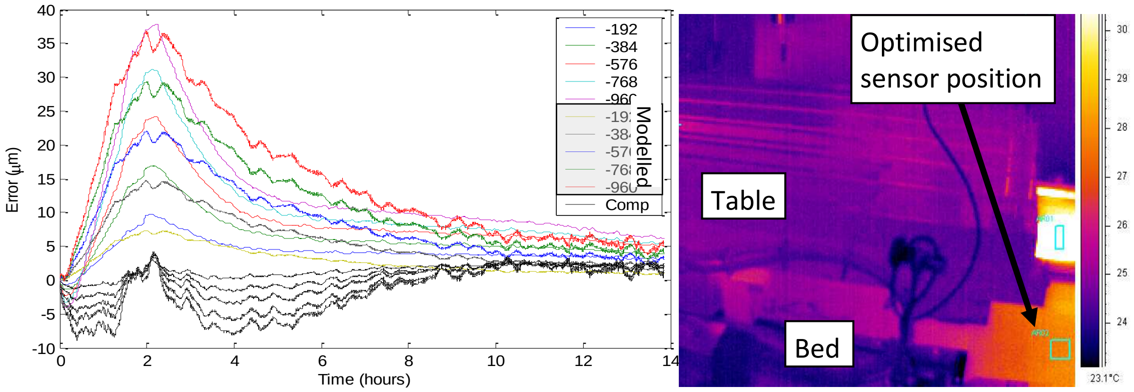

Figure 1. Cartesian axis compensation from sensor location optimised using thermal imaging

4 Correlation search using FEA

Because on-line testing is generally disruptive to production, FEA was applied to sensor optimisation for environmental error. Recently, such simulations have shown good accuracy and can include a varied set of conditions. On the small 3-axis machine model, a node on the rear of the column was found to be optimal. The result was validated on the machine over 2.5 days is shown in Figure 2.

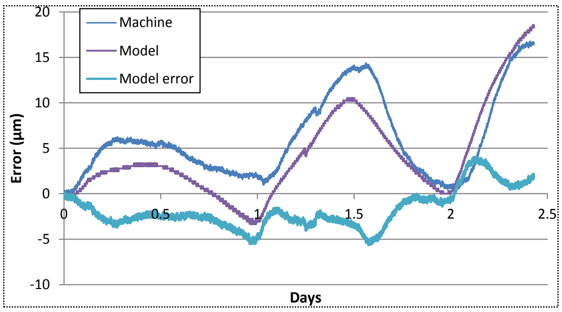

Figure 2. Optimal sensor model and measured environmental error

5 References

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