Thermal error modelling of a three axes vertical milling machine using Finite element analysis (FEA)

Original Citation


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Abstract
The errors caused by thermal deformation directly affect the precision of a machine tool. Temperature changes of machine tool structures occur as a result of two reasons: firstly, internal heat sources like belt drives, motors, and bearings; secondly, external heat sources such as ambient temperature changes of the shop work. These changes in machine tool structure temperature cause the heat to flow and because of this; the machine tool element deforms.

Objectives
- Measuring temperature gradient and displacement of machine tool
- Creating a FEA Model and simulating the temperature and displacement of machine tool
- Comparing the experiment and simulated data

Methodology
Experiment: the experiment set up divided into parts
1. Thermal imaging camera set up
2. Non-Contact displacement Transducer Sensors (NCDT)

Heat transfer conditions
- Conduction: $Q = KA \left( \frac{dT}{dx} \right)$
- Convection: $Q = hA \Delta T$
- Radiation: $Q = \varepsilon \sigma A T^4$

Where $Q$: heat rate (W), $K$: (W/m°C) thermal conductivity, $dx$: length (m), $\Delta T$: temperature difference (°C), $T$: surface temperature (°C), $\varepsilon$: body emissivity, $t$: time (sec), $\sigma$: Stefan Boltzmann Constant (W/m²°C⁴).

Radiation is negligible due to the low working temperatures.

Creating FEA model and simulating it

Model simulation
The FEA was carried out using Dassault Systemes Simulation (Part of the Solidworks suite of software) to predict the temperature gradient and the spindle thermal deformation.

Results

<table>
<thead>
<tr>
<th>Correlation coefficients (R)</th>
<th>Temperature</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.92</td>
<td>0.97</td>
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</table>

Conclusion
The accurate simulations can be used to predict errors under different operating conditions and to develop compensation models. Thermal error could be reduced to just 4 μm in the Z and Y axis directions from 35 and 20 μm respectively.