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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 ambient temperature change of the workshop. 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 of machine tools
- Creating a FEA Model and simulating the temperature and displacement of machine tools
- Comparing the experiment and simulated data

Methodology
Experiment: the experiment setup divided into parts

1. Thermal imaging camera set up

   Thermal imaging camera set up and a thermal image at end heating cycle

2. Non-Contact displacement Transducer Sensors (NCDT)

   NCDTs use a magnetic field to sense the target

Boundary conditions

<table>
<thead>
<tr>
<th>Heat transfer</th>
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<tbody>
<tr>
<td>Conduction</td>
</tr>
<tr>
<td>$Q = KA(\frac{dT}{dx})$</td>
</tr>
<tr>
<td>Convection</td>
</tr>
<tr>
<td>$Q = hA(\Delta T)$</td>
</tr>
<tr>
<td>Radiation</td>
</tr>
<tr>
<td>$Q = \varepsilon \sigma AT^4$</td>
</tr>
</tbody>
</table>

Where $Q$ heat rate (W), $K$ (W/m K) thermal conductivity, $x$ length (m), $\Delta T$ temperature difference (°C), $T$ surface temperature (°C), $\varepsilon$ body emissivity, $t$ time (sec), $\sigma$ The Stefan Boltzmann Constant (W/m$^2$K$^4$).

Radiation is negligible due to the low working temperatures

Heat transfer balance equation

\[ Q = (mc_p)\Delta T + h\Delta T \]

Where $m$ mass Kg, $c_p$ specific heat ($\frac{J}{kg\cdot°C}$)

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

Heat power (Non linear heat source relationship)

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