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

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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 bearing. Secondly, external heat sources such ambient temperature change of the work shop. These changes in machine tools structure temperature cause the heat to flow and because of this the machine tool element deforms.

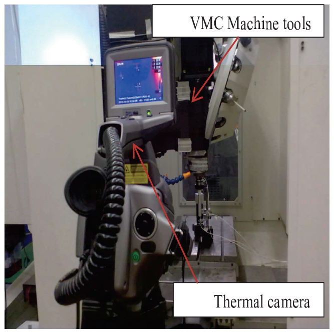
Objectives

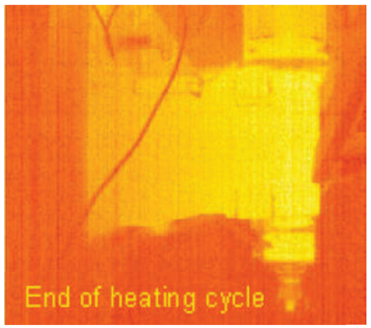
- Measuring temperature gradient and displacement of machine of machine tools
- Creating a FEA Model and simulating the temperature and displacement of machine tools
- Comparing the experiment and simulated data

Methodology

Experiment: the experiment set up divided into to parts

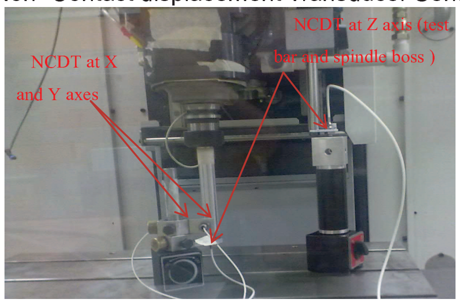
1- Thermal imaging camera set up





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

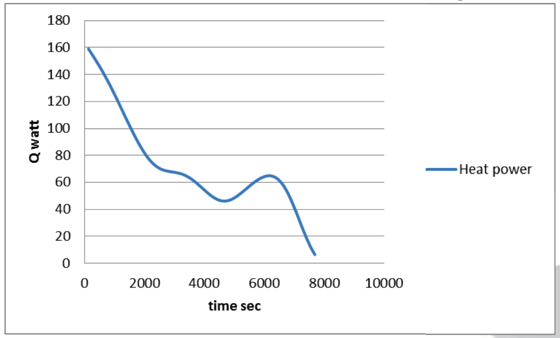
Heat transfer Conduction	Heat transfer convection	Heat transfer radiation
• $Q = KA(\frac{dT}{dx})$	• $Q = hA(\Delta T\ )$	• $Q = \ \varepsilon\, \sigma\, A\, T^4$

Where Q heat rate (W), K (W/m. ℃) thermal conductivity, dx length (m) , ΔT temperature difference (℃), T surface temperature (℃), ε body emissivity, t time (sec), σ The Stefan Boltzmann Constant $(\mathrm{W}/m^2 {}^{\circ}\mathrm{C}^4)$.

Radiation is negligible due to the low working temperatures

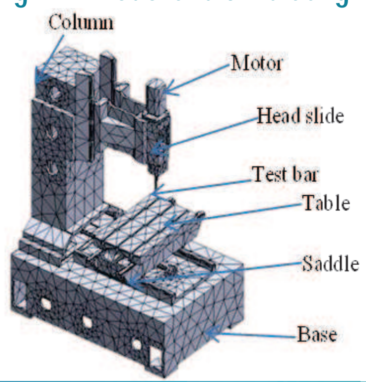
Heat transfer balance equation
• $Q = (mC_p\Delta T)/t + hA\Delta T$

Where m mass Kg, C_p specific heat $(\frac{j}{kg.^{\circ}C})$



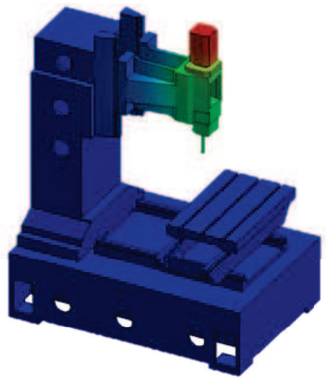
Heat power (Non linear heat source relationship)

Creating F E A model and simulating it

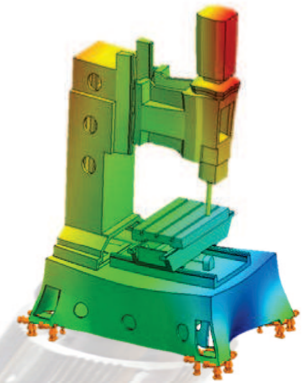


Model simulation

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.

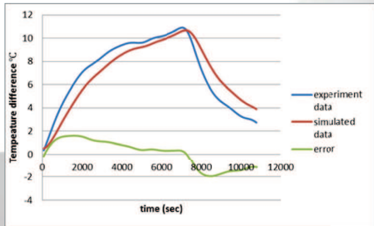


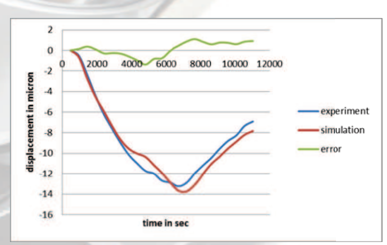
Machine structure temperature gradient



Machine structure deformation

Results





Results comparison

Correlation coefficients (R)	Temperature	Displacement
	0.92	0.97

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.