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Estimation of thermal parameters for high-speed motorized spindle using inverse optimization method

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Agenda

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- Background
- Introduction
- Methodology
- Forward problem
- Work flow in modefrontier
- Conclusion

Background

- Demand for **high precision** and **low tolerance** product has significantly increased the application of CNC machine tools in a wide range of industries, such as Aerospace, Defence, Medical devices, Automotive industry, Precision instrumentation, Optics and Semiconductor manufacturing.

Expectations from Machining Industry

- High level of accuracy
- Consistent quality
- Low error rate
- Less material waste
- Increased efficiency cost-effective

Courtesy: Gemsons

- One of the major **challenges** associated is **thermal management**

Introduction

Machine tool error

- Error represents deviations of the cutting tool point from the theoretical position relative to the workpiece.

Thermal Error

- The temperature gradients causes dimensional changes in the machine tool structure.

Heat sources

Internal

- Spindle bearings
- Motor
- Cutting tool

External

- Ambient temperature
- Surrounding machine
- Light radiation

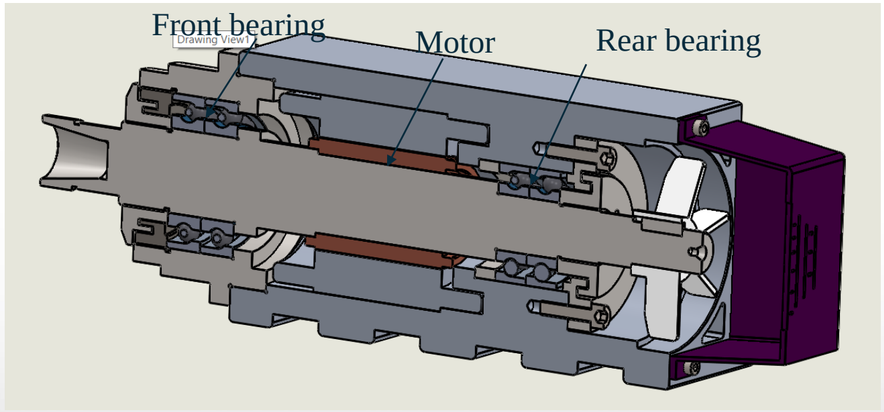


Fig.1.1 Heat sources in spindle

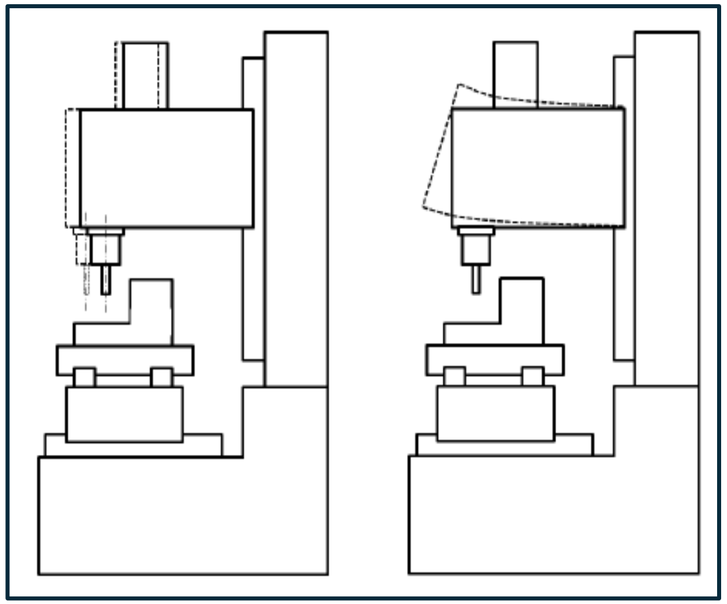


Fig. 1.2 Actual & deformed state of vertical milling

Thermal Error effects

- Spindle axial growth
- Spindle radial drift
- Distortion of the spindle region
- Work piece deformation

Importance of finding Q

- Thermal damage prevention
- Design optimization(modelling)
- Maintenance and lubrication
- Improving the efficiency
- Cost saving

- **Thermal error** constitute major portion of the total **tool positioning error** largely affects the machine tool accuracy.

Introduction

- Traditional method to find heat generation and thermal properties

Experimental: This technique involves conducting physical experiments on the spindle under controlled conditions for temperature measurement

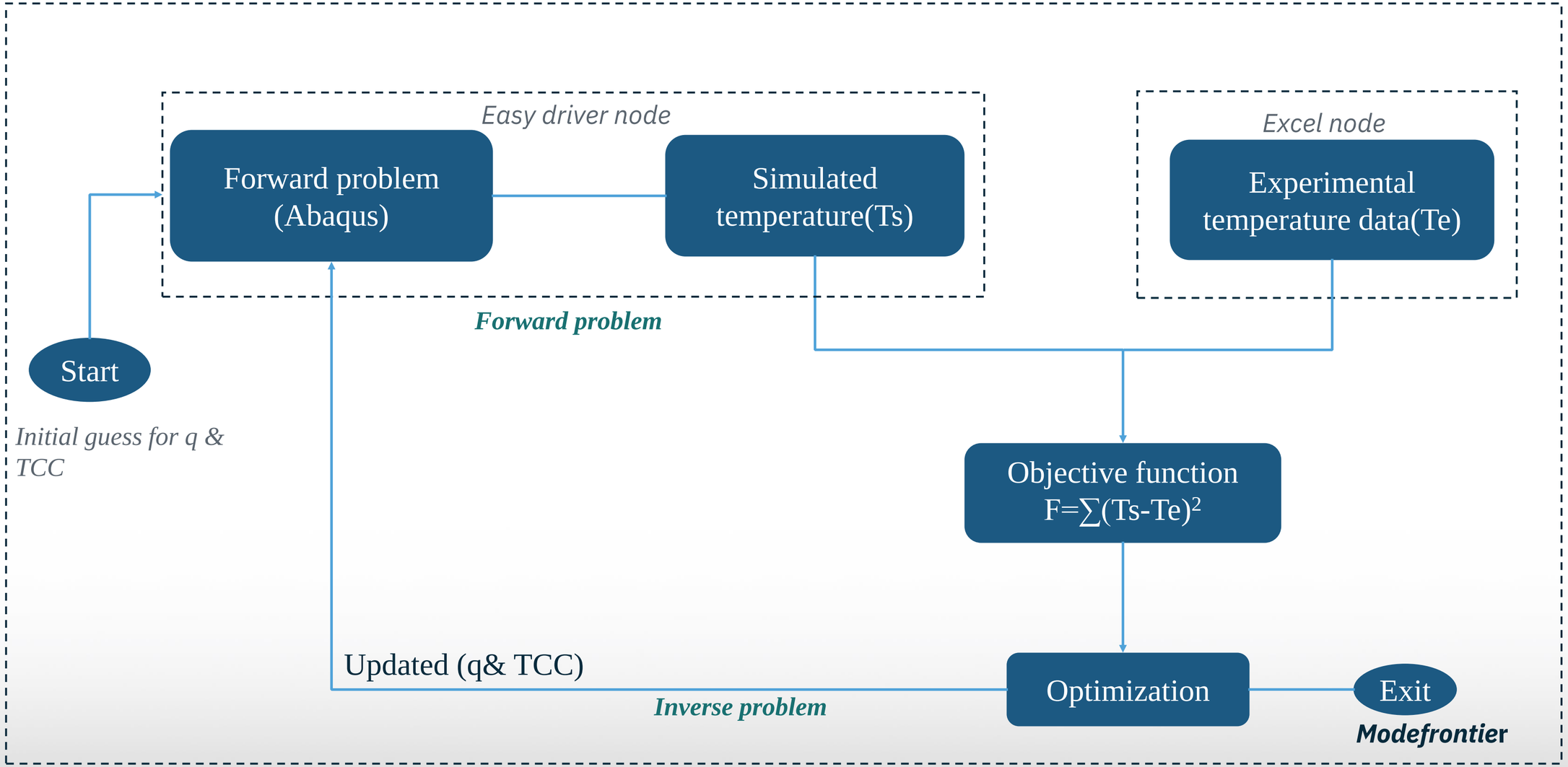
Analytical: Analytical relations are often used to find heat sources and thermal contact conductance(TCC). However, these relations are usually derived and simplified based on specific conditions, which do not accurately capture real-world scenarios

Numerical: Development of numerical models involves either experimentally obtained or analytically evaluated thermal parameters to understand spindle thermal behaviour

- Simulation-Driven method

Inverse method: present work proposes a comprehensive model which includes a 3D finite element model and inverse method using mode FRONTIER to estimate the thermal parameters using the experimentally measured temperature in the spindle housing with minimum sensors

Methodology



Forward problem

- Inverse problem can't be solved without referring to the solution of the direct problem
- Temperature solution of the direct problems is received through solving the FE thermal model in Abaqus
- Transient thermal simulation is carried out in Abaqus, with some initial gauss (heat flux); it's solved to get the temperatures

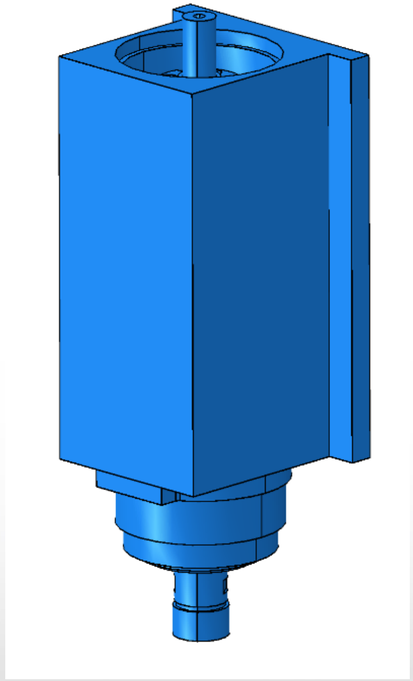


Fig.2.1 Spindle Assembly

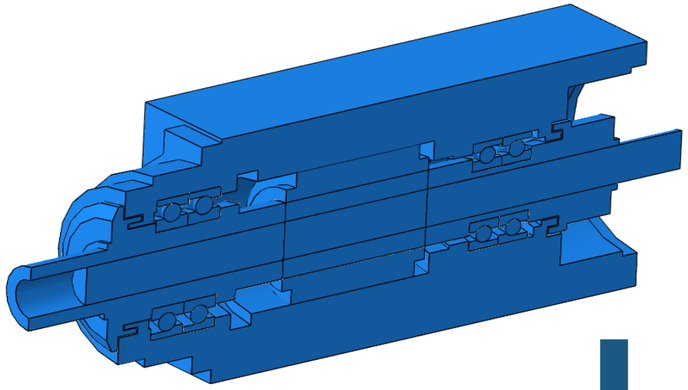


Fig.2.2 simplified geometry

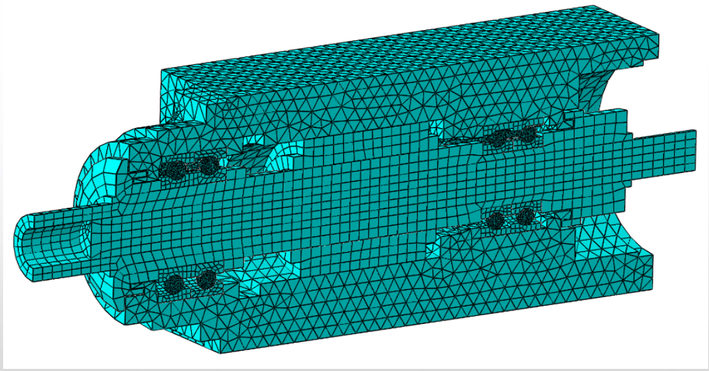


Fig.2.3 Meshed model

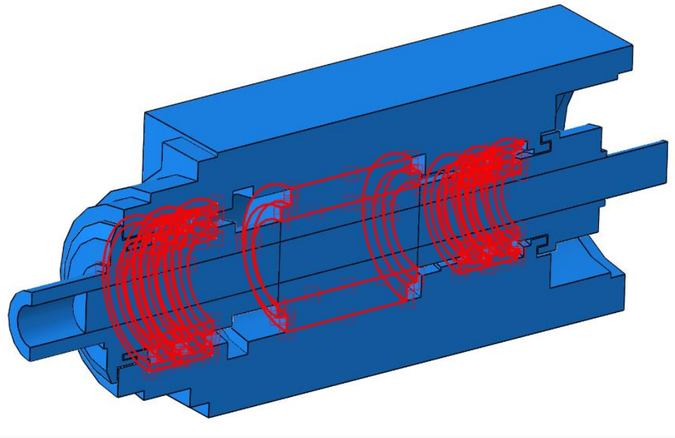


Fig.2.4 Interactions and Boundary Conditions

Workflow in mode-frontier

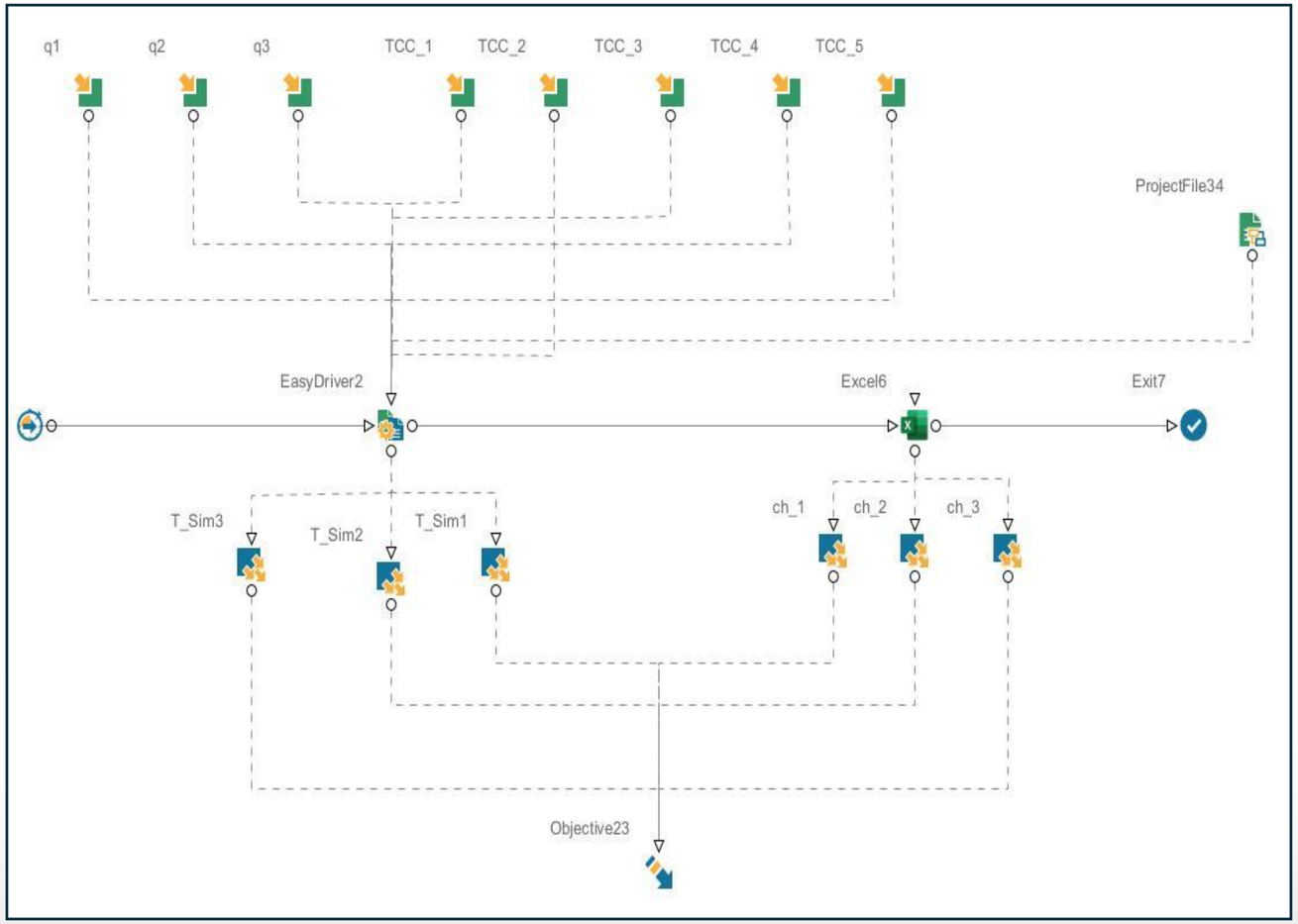


Fig.3 Work flow in modefrontier

- Input node → Input variables q1,q2,q3 and TCC
- Easy driver → Abaqus input file integration
- Excel node → Initialising experimental data
- Project file → Python script to extract simulated temperature from Abaqus
- Output node → Simulated and experimental temperature vector

Conclusion

- Proposed novel comprehensive framework is more robust and accurate in estimating critical thermal parameters, *i.e., heat sources, and TCC*
- This approach intended to avoid the dependencies on analytical expressions for evaluating the thermal parameters by directly using the measured temperature
- Combining the inverse method and FEA enabled us to accurately predict the high-speed motorized spindle's heat source values. The proposed system effectively estimated these critical parameters by utilizing experimental temperature data and iteratively adjusting the parameters through the inverse method.

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Thank you!

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