



SIMPACK User Meeting 2004  
Wartburg, Eisenach, November 2004

***The Modelling of a Machine Tool  
with Thermally Induced Displacements***

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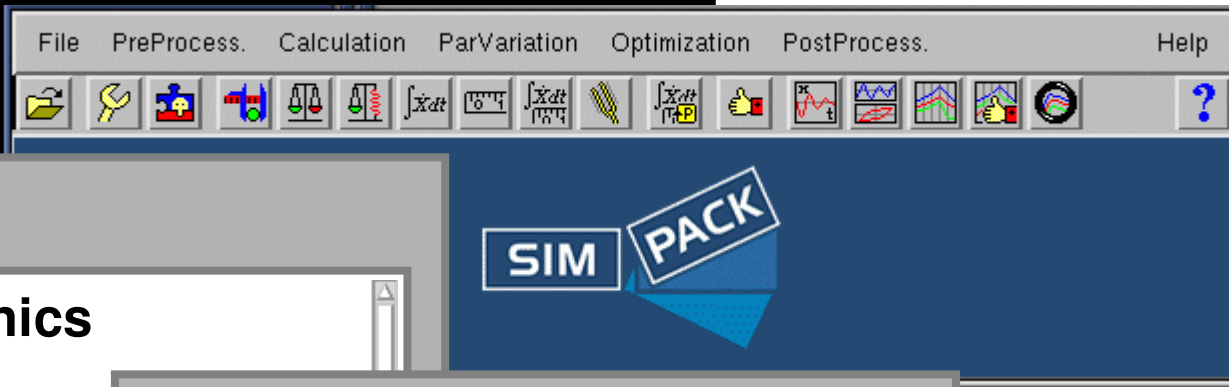
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**Institute of Robotics and Mechatronics  
Vehicle System Dynamics  
DLR Oberpfaffenhofen**





**DLR** Institute of Robotics and Mechatronics  
Vehicle System Dynamics



### Automotive

**Terramechanics**  
Off-Road  
Contact  
Crash  
Real Time  
Suspensions

### Wheel/Rail

**Elastic Wheels & Rails**  
Wear, Hunting Motion  
Reliability Analysis  
Sidewind  
**Bifurcation Analysis**  
**Hunting Motion**

### General

**Spatial Track**  
Roller Coaster  
Adaptive Structures  
Active Damping  
**Thermoelasticity**  
**Thermal Displacements**

**SIMPACK related Research @ DLR**



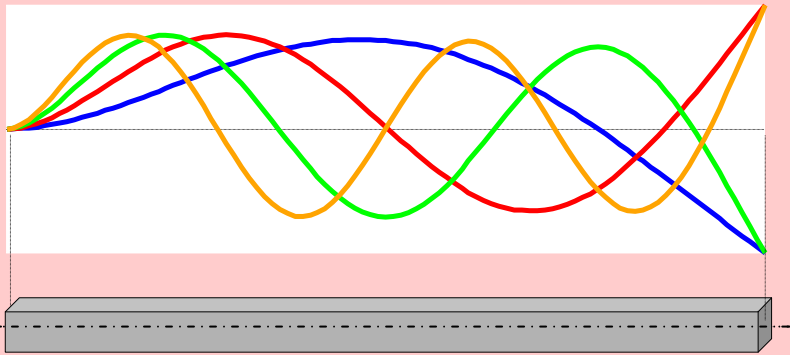
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  - **Stationary Displacement Fields = Thermal Response Modes**
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# Modal Multifield Approach

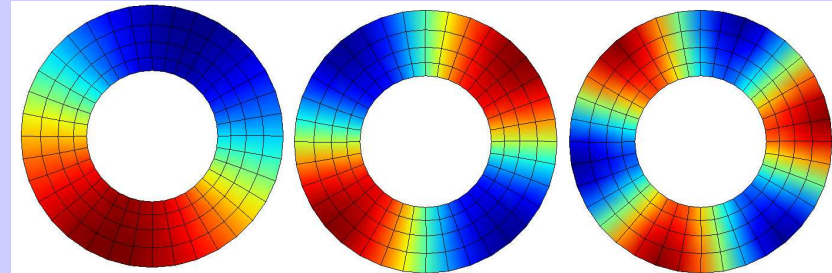
Displacement Modes:

$\Phi_u$



Thermal Modes:

$\Phi_\vartheta$



$$u = \Phi_u z_u$$

$$\vartheta = \Phi_\vartheta z_\vartheta$$

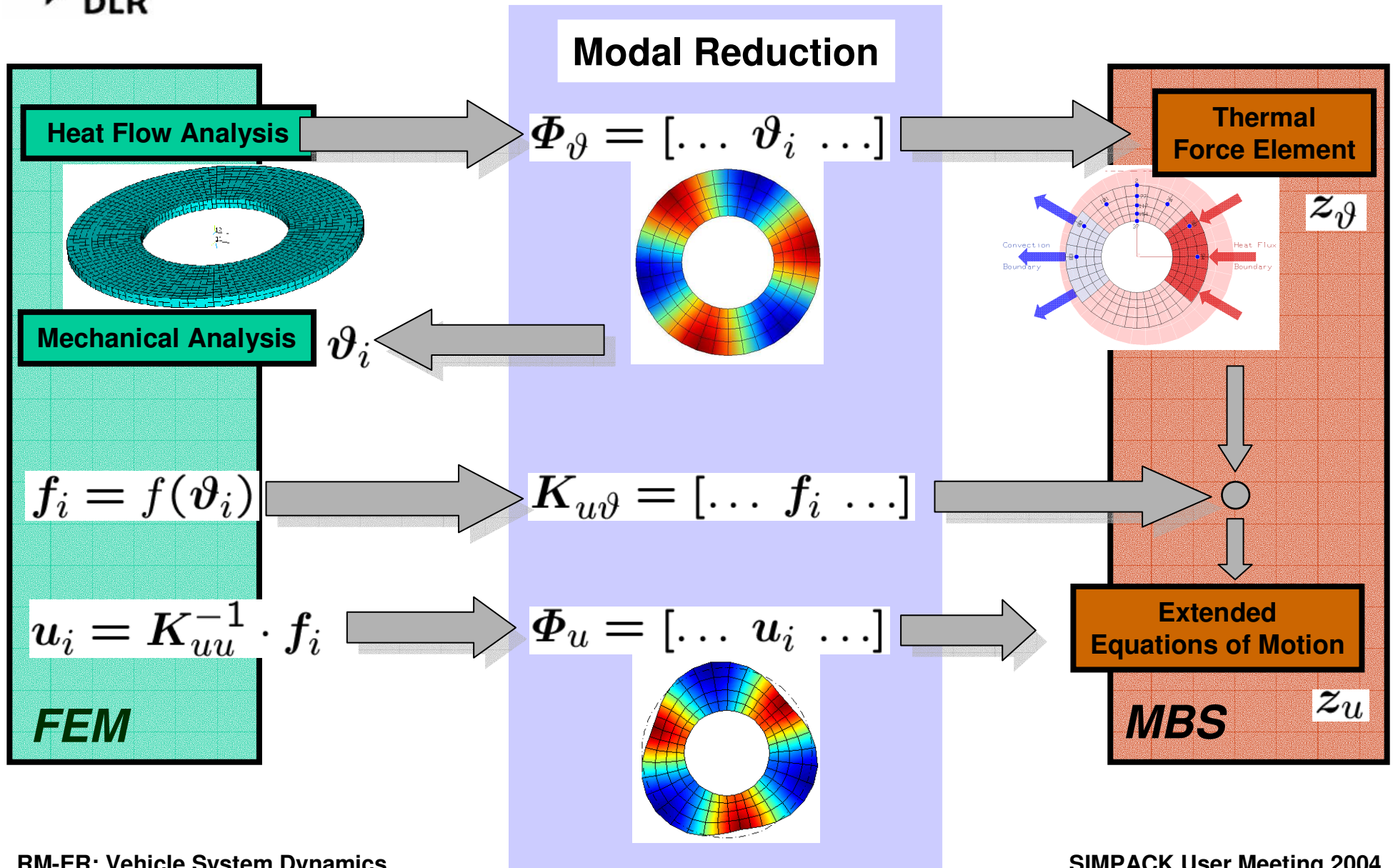
$$\varepsilon = (\nabla_u \Phi_u) z_u = B_u z_u$$

$$K_{uu} = \int B_u^T H_c B_u dV$$

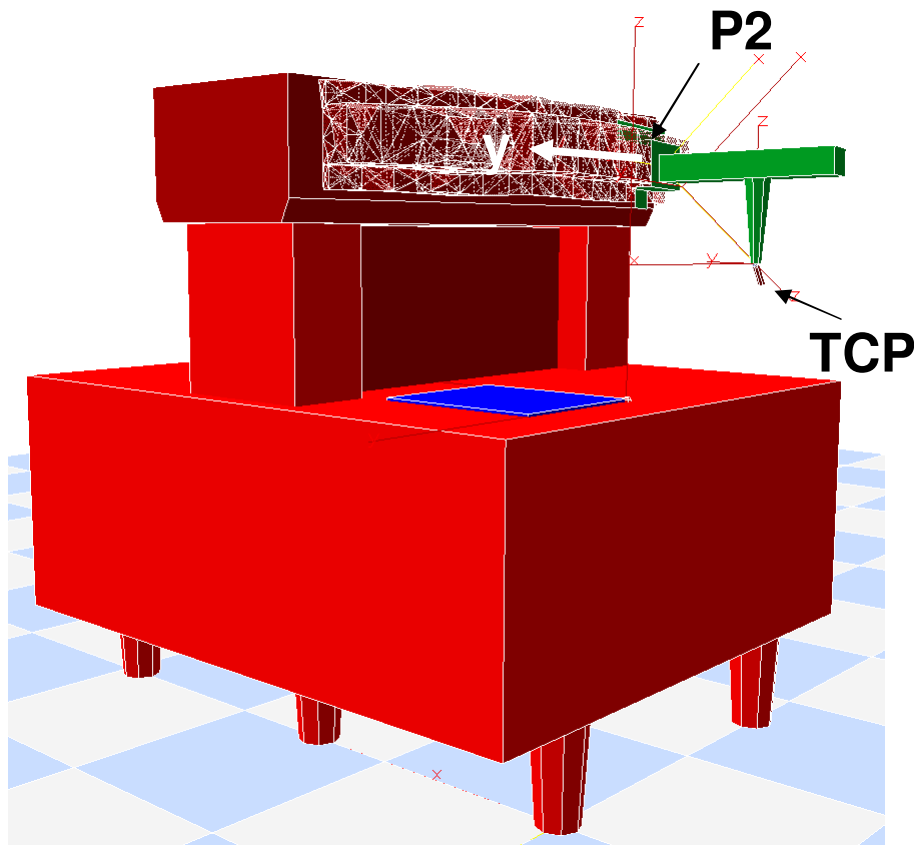
$$K_{u\vartheta} = \int B_u^T H_\lambda^T \Phi_\vartheta dV$$

$$M_{uu} \ddot{z}_u + K_{uu} z_u = h_u + K_{u\vartheta} z_\vartheta$$

# Thermal Response Modes

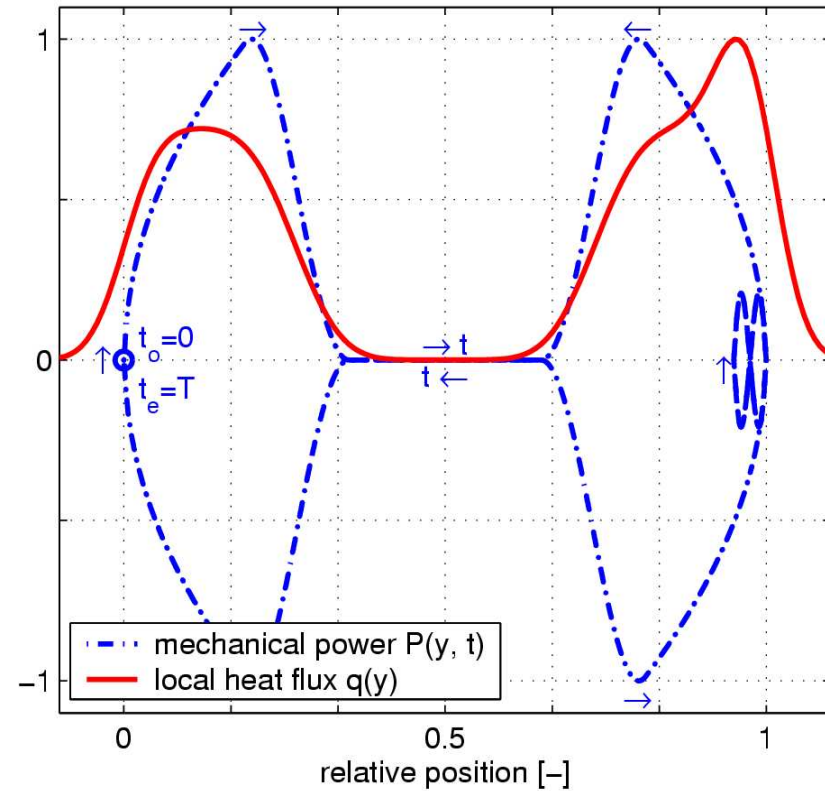
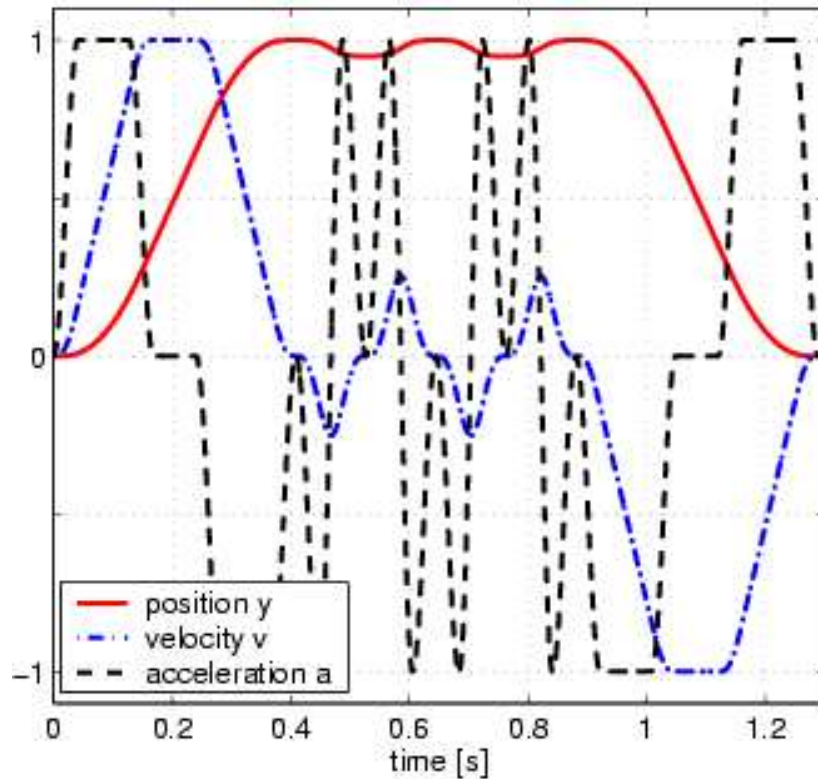


# Machine Tool: The Name of the Game



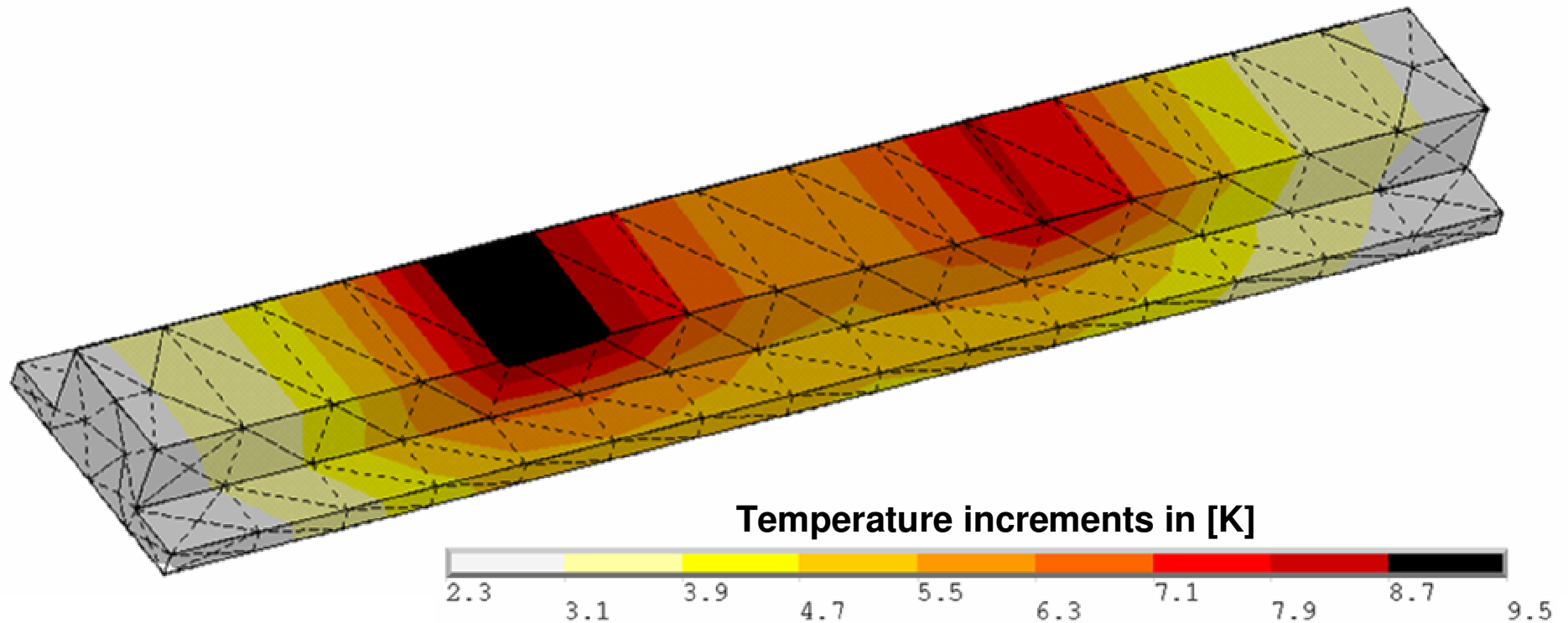
- Point-to-Point working task
- Drives with excellent dynamical properties for high performance !
- High accuracy demanded !
- Thermal loads caused by drives or working task
  - relevant displacements ?
  - system-dynamical description ?
  - CAE work flow ?

# Machine Tool: Kinematic Scenario



$$\left. \begin{aligned} \bar{q}(t) &= \bar{q}(t + nT) \\ \bar{y}(t) &= \bar{y}(t + nT) \\ n &\rightarrow \infty \end{aligned} \right\} \implies -\lambda \vartheta_{,yy} \approx q(y)$$

# Machine Tool: Thermal Modes

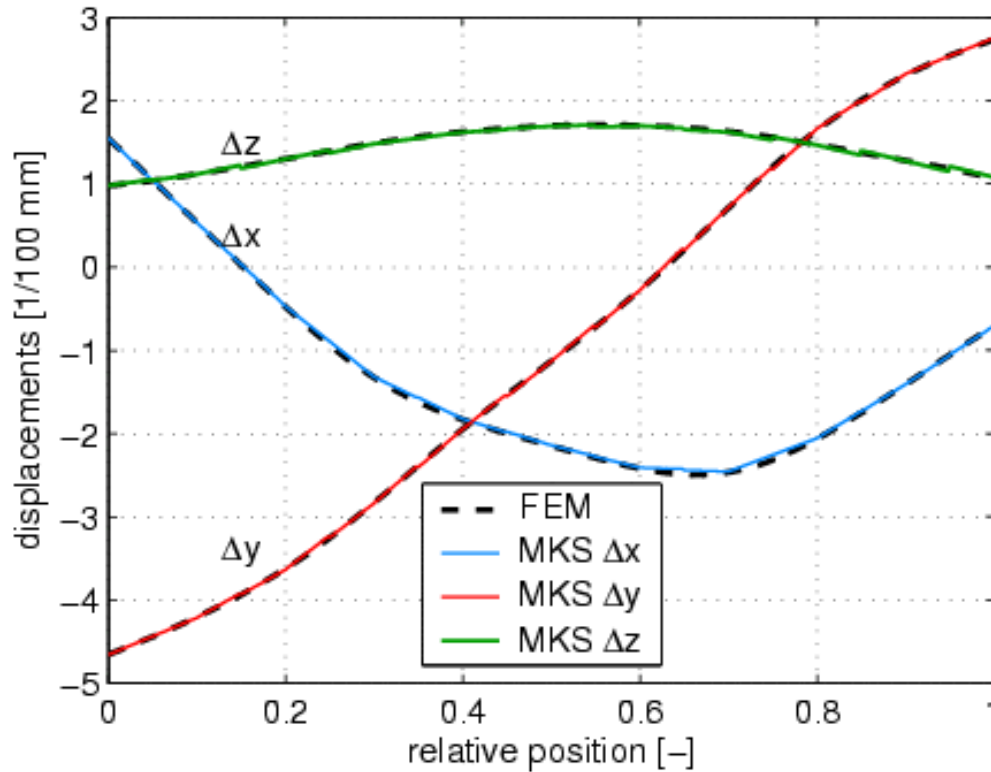


2 steady state heat transfer FEM-solutions  $\Rightarrow$  2 thermal modes  $\Rightarrow$  2 thermal response modes



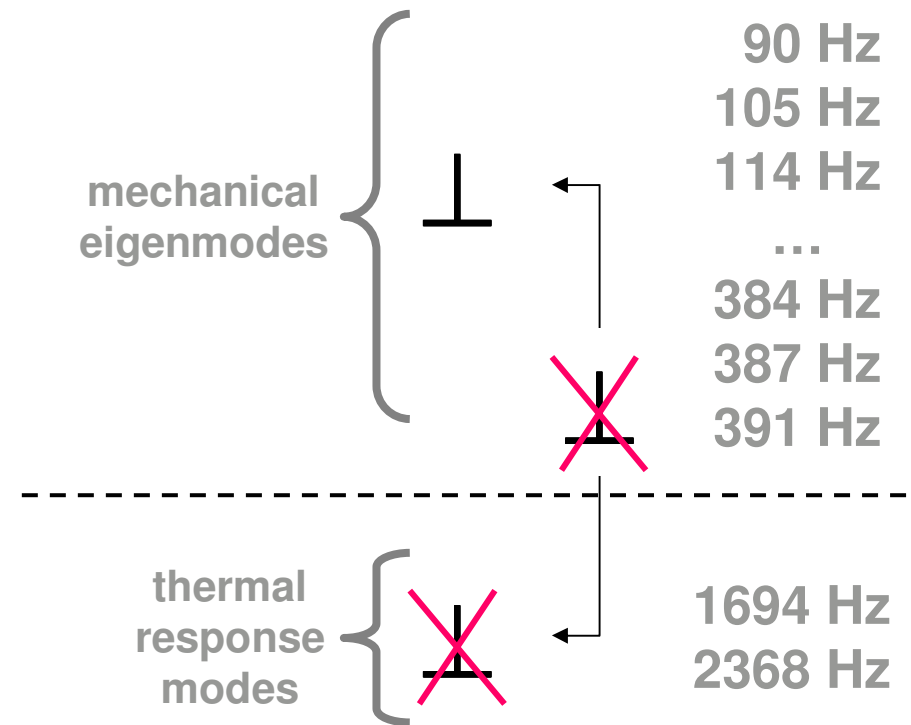
# Machine Tool: Thermal Response Modes

## Comparison FEM vs. MBS



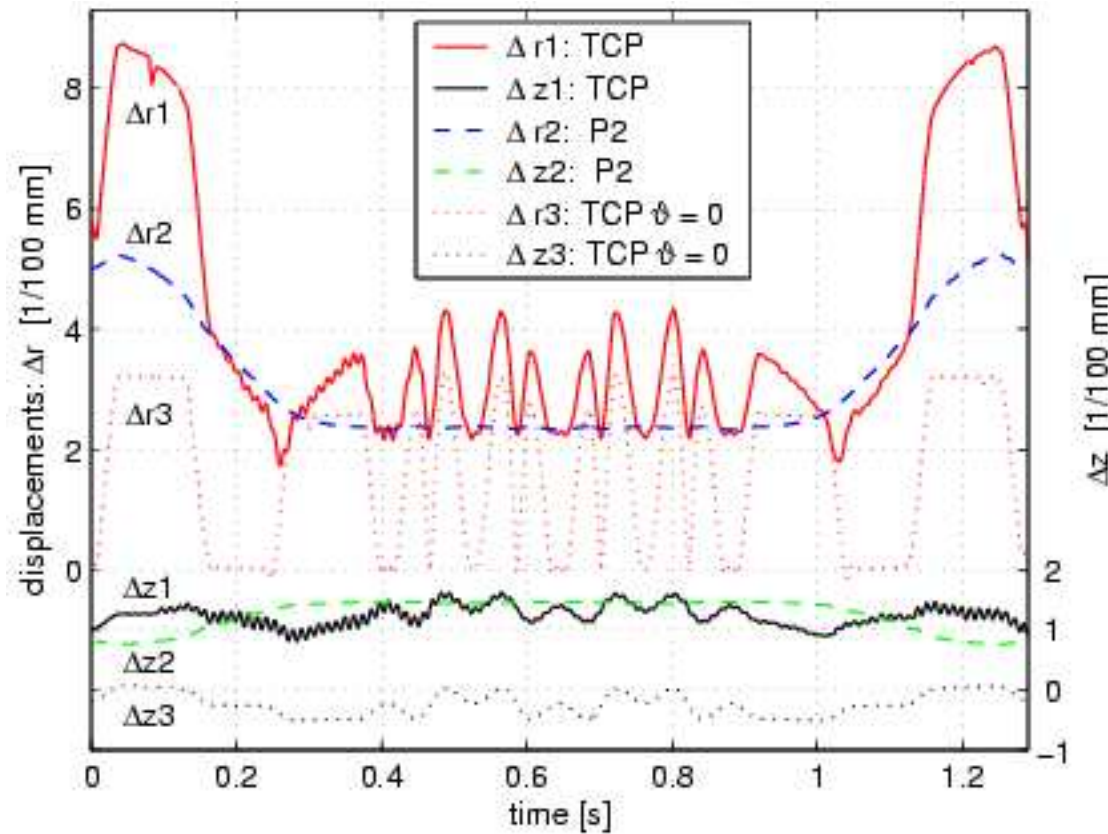
Thermal response modes  
FEM : MBS  $\approx$  1:1

## Eigenvalue Analysis



Eigenmodes and thermal response modes were weakly coupled.

# Machine Tool: Dynamic Simulation



TCP: tool center point

P2: reference point, moving along the machine base with predefined kinematics

$\Delta r_3$ ,  $\Delta z_3$ : reference displacements of TCP without thermal loads

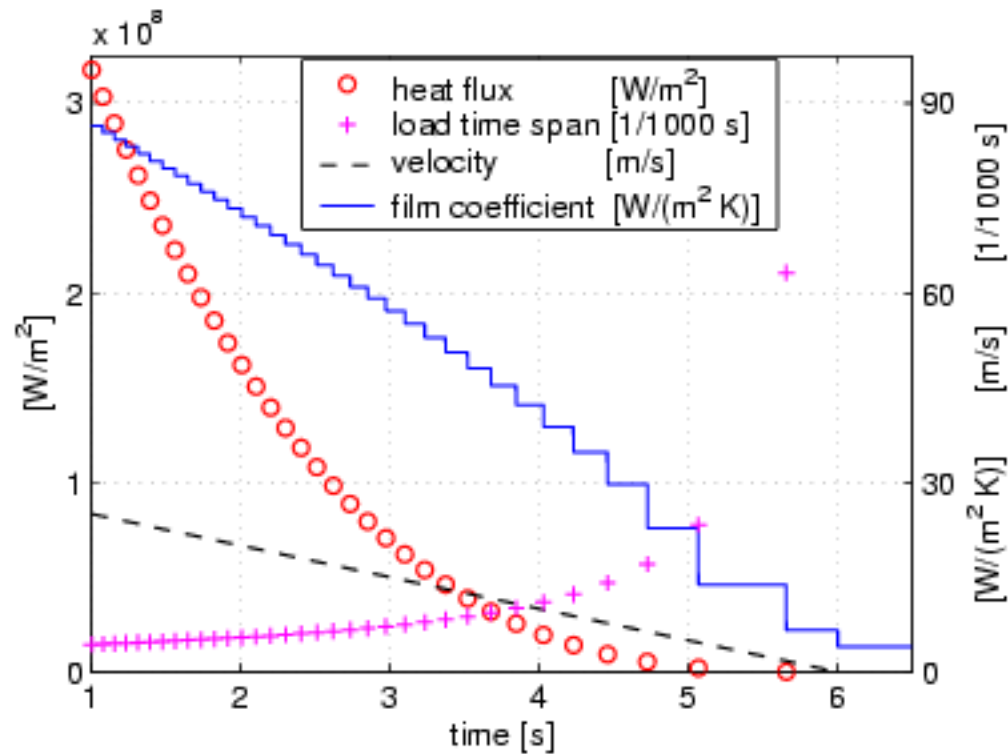


# Machine Tool: Conclusions

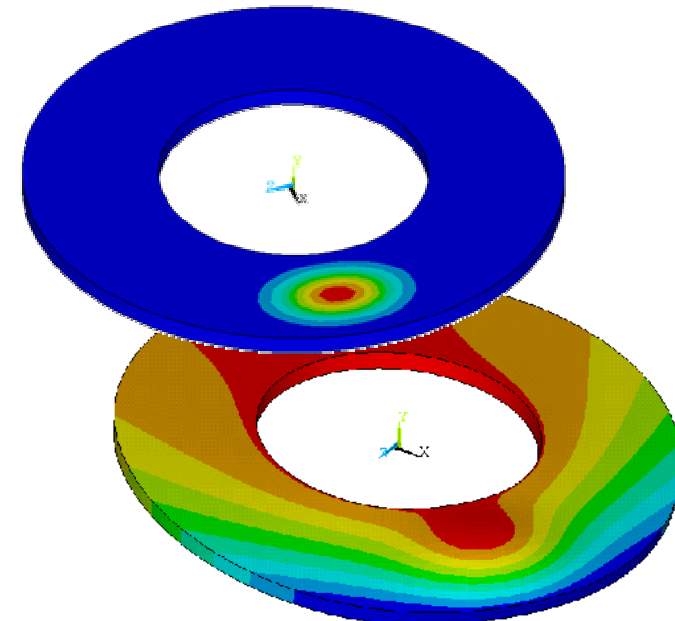
- **Description and CAE workflow of thermal displacements is feasible.**
- **In general, modes are not orthogonal.**
- **High frequency modes are involved.**
  
- **What about transient temperatures ?**
  - **Is *Duhamel's Assumption* still valid ?**  
If yes, thermal displacements could generally be provided as driven equilibrium solutions !
- **What about more localised temperature peaks ?**

# Outlook: Brake Disc

## Hot Spot Scenario



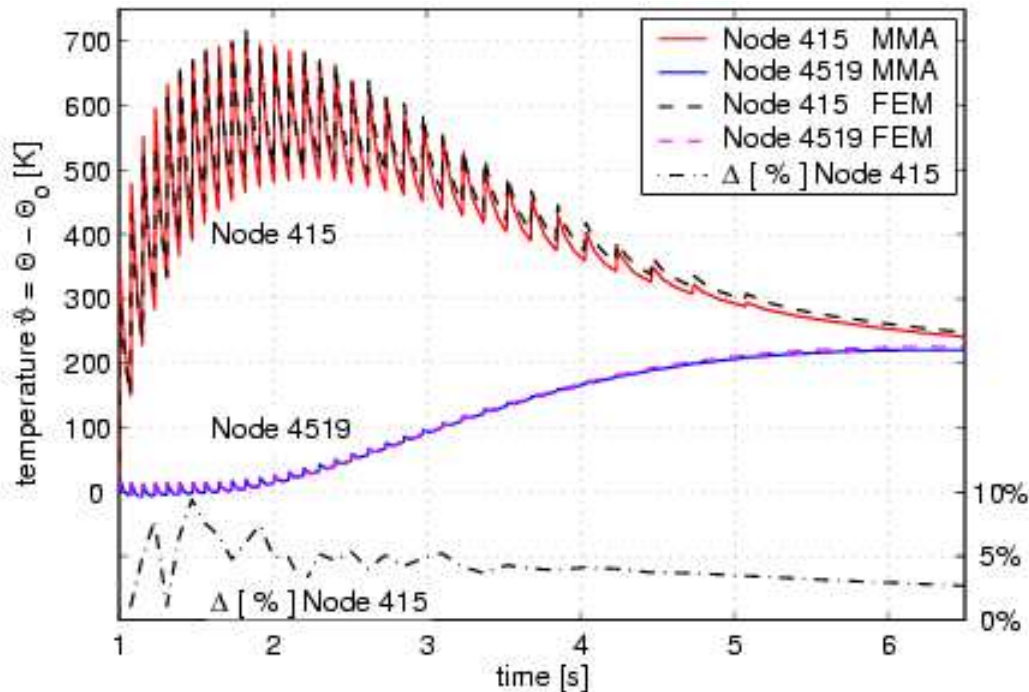
Load definitions are based on a midsize car at 90 km/h that stops, and are applied continuously in space and time.



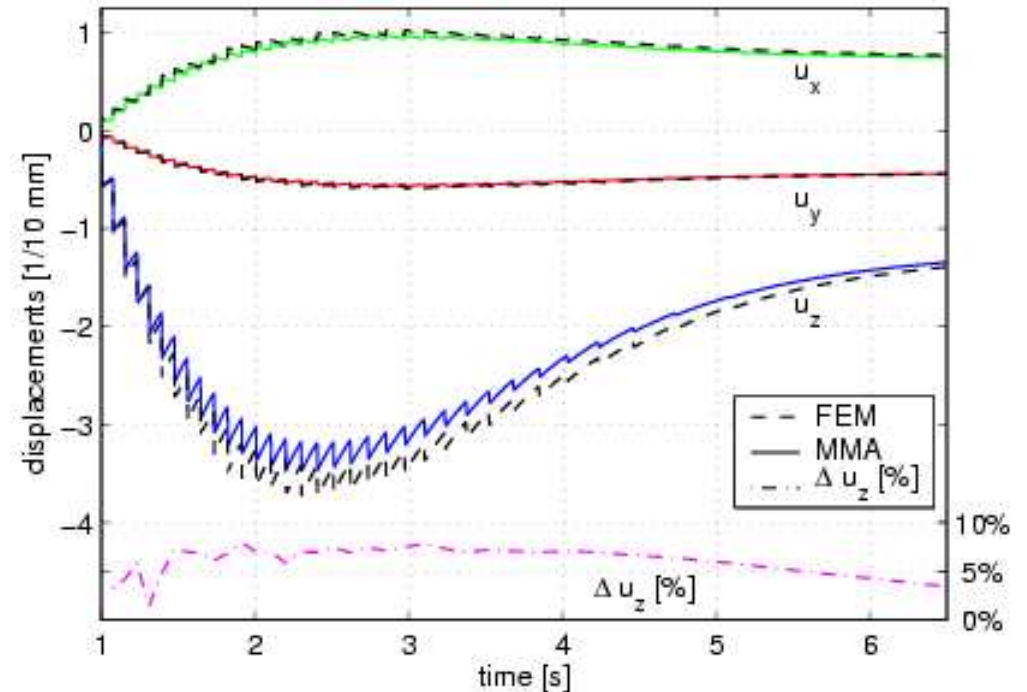
Temperatures and axial displacements of a single hot spot after 2,199 s, obtained by FEM (reference solution).

# Outlook: Brake Disc

## Preliminary Results



Temperatures at Node 415 and Node 4519  
(central to the hot spot on both  
surfaces of the disc)



Displacements of Node 20  
(on the outer edge of the disc)

MMA: modal multifield approach