COMSOL CONFERENCE
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TEHL Simulation of Gear Contacts

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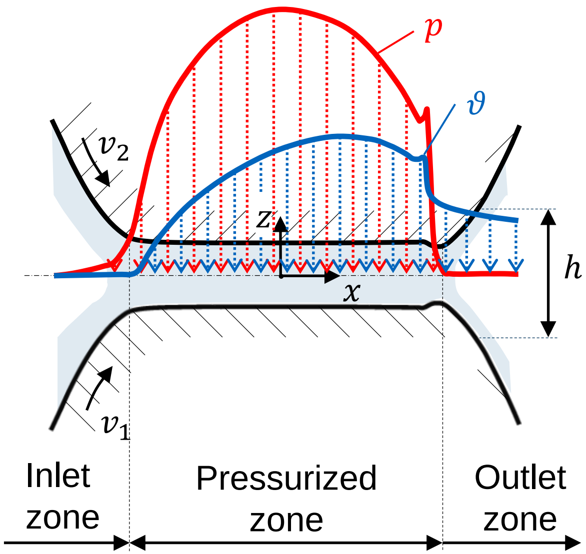
Outline

- Introduction
- Problem Description
- Model Implementation
- Exemplarily Results
- Conclusion

Introduction

- TEHL contact: Back-coupling of hydrodynamic and deformation in lubricated contacts (Bartel 2009)
- Frequently occurring in drive technology and thus in gear drives
- Significant influence on friction and damage behavior of gears



Very small scales in space and time in TEHL contacts require numerical simulation to capture the tribological processes of gears in detail

- Using Multiphysics is necessary to simulate TEHL contacts
- Study focusses on the implementation of a TEHL simulation model for gear contacts

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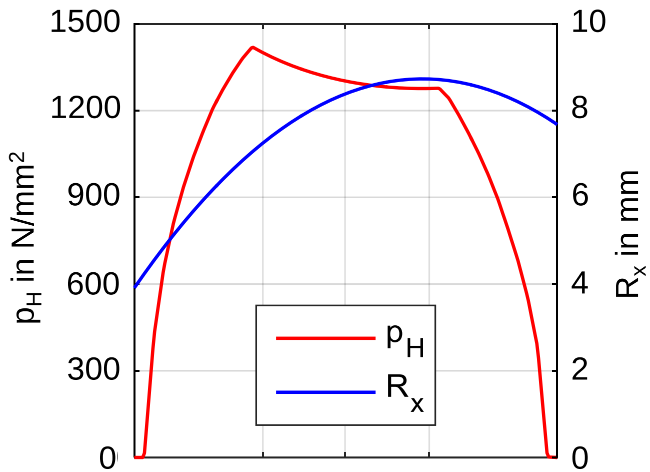
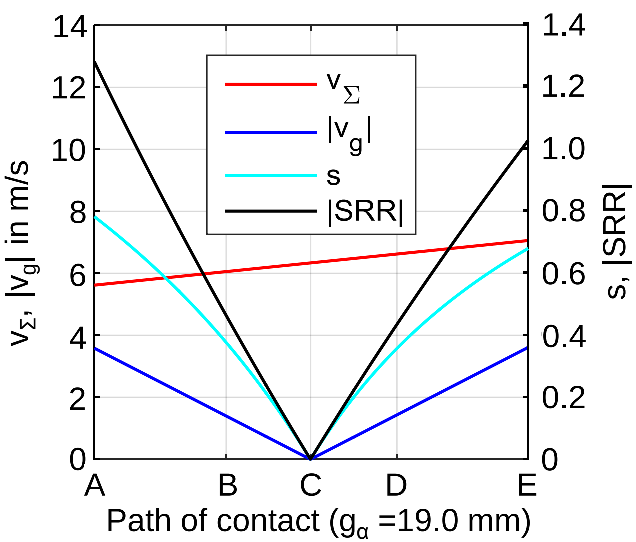
Problem Description





Gear Parameter

Gear type	FZG type Cmod
Centre distance a in mm	91.5
Number of teeth $z_1 : z_2$	$16 : 24$
Normal module m_n in mm	4.5
Pressure angle α in °	20
Face width b in mm	14
Tip relief C_{a1}, C_{a2} in μm	35

Operating Condition

Pinion Torque T_1 in Nm	183
Pinion bulk temperature $\vartheta_{M,1}$ in $°C$	90
Pitch line velocity v_t in m/s	8.3

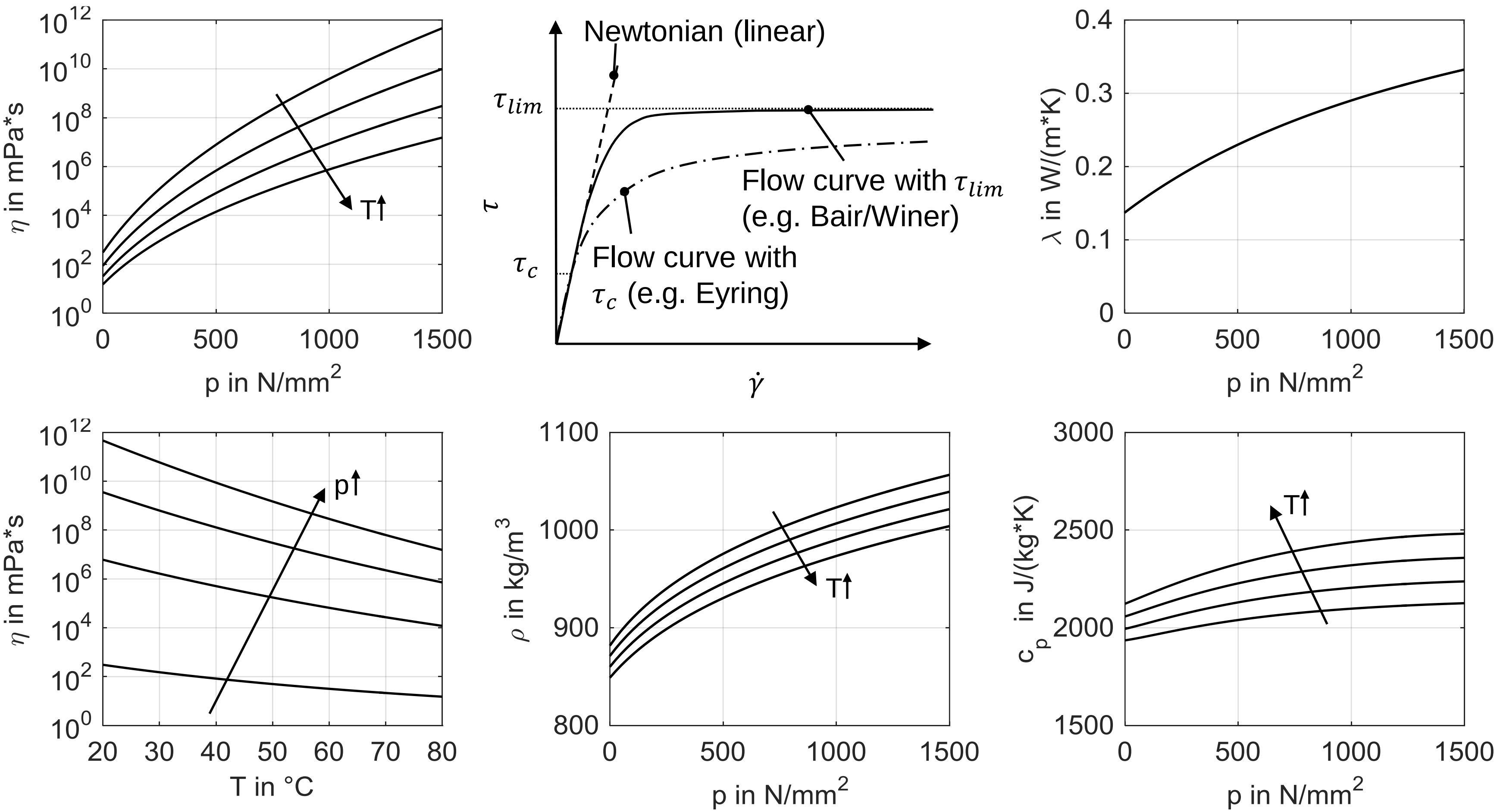
Lubricant Parameter

Lubricant type	MIN100
$\upsilon\ (40°C)$ in mm^2/s	95.0
$\upsilon(100°C)$ in mm^2/s	10.0
$\rho_f(15°C)$ in kg/m^3	885

Ziegltrum, Lohner, Stahl;
43rd Leeds-Lyon Symposium
on Tribology, Leeds, UK (2016)

Problem Description

Dependency on Temperature, Pressure and Shear Rate



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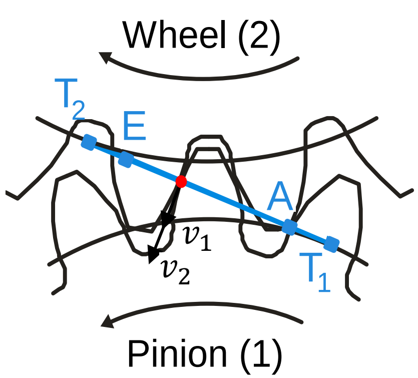
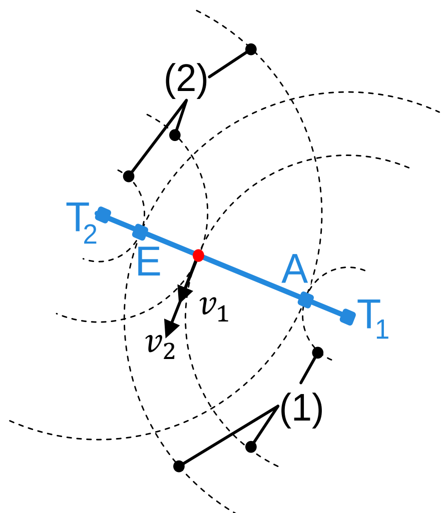
Model Implementation

- Transient TEHL contact along the path of contact of gears can be interpreted as sequential instantaneous contacts of two rolling elements
- In TEHL simulations, this contact is usually further simplified to an equivalent contact between a single (inelastic) roller and an elastic flat body

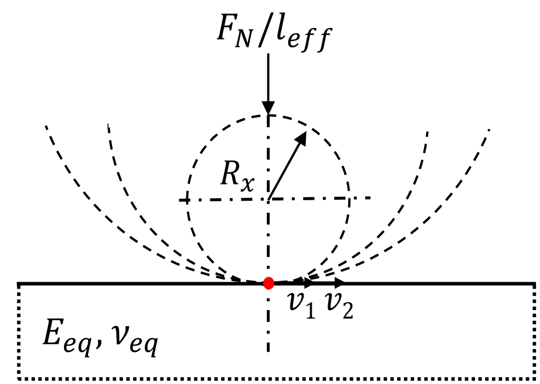
Gear contact



Model contact



Equivalent contact



Lohner, Ziegltrum, Stemplinger, Stahl;
doi: 10.1155/2016/6507203 (2016)

Model Implementation

FEM-based TEHL simulation model with non-Newtonian fluid behavior

- **Hydrodynamics** $(\boldsymbol{\Omega_P})$**:**

$$\frac{\partial}{\partial x}\left[\frac{\partial p}{\partial x}\int_0^h \rho\left(\int_0^z \frac{\tilde{z}}{\eta}d\tilde{z} - \int_0^z \frac{1}{\eta}d\tilde{z}\,\frac{\int_0^h \frac{z}{\eta}dz}{\int_0^h \frac{1}{\eta}dz}\right)dz\right] + \frac{\partial}{\partial x}\left[\frac{v_2 - v_1}{\int_0^h \frac{1}{\eta}dz}\int_0^h \rho\left(\int_0^z \frac{1}{\eta}d\tilde{z}\right)dz + \int_0^h \rho dz \cdot v_1\right] + \frac{\partial}{\partial t}\int_0^h \rho dz = 0$$

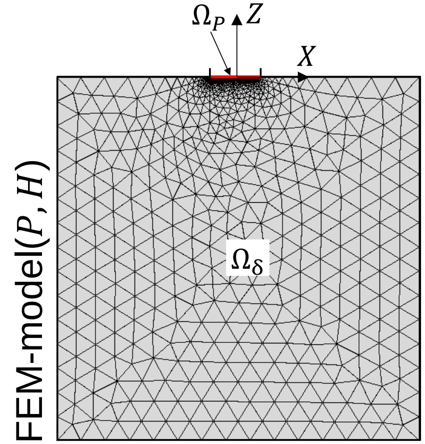
- **Contact mechanics** $(\boldsymbol{\Omega_\delta})$**:**

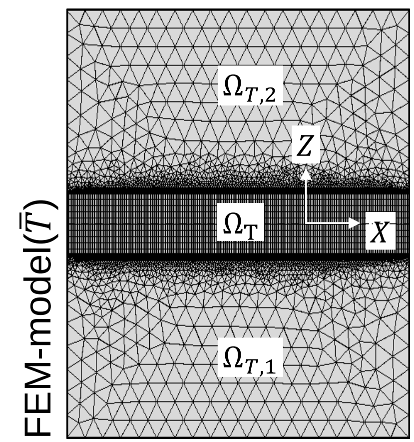
$$h = h_0 + \frac{x^2}{2R_x} + \delta - \Re \quad \text{with} \quad \int_\Omega p\, d\Omega = F_N/l_{eff}$$

- **Energy conservation** $(\boldsymbol{\Omega_T}, \boldsymbol{\Omega_{T,1}}, \boldsymbol{\Omega_{T,2}})$**:**

$$\rho c_p\left(\frac{\partial\vartheta}{\partial t} + u\frac{\partial\vartheta}{\partial x}\right) - \left[\frac{\partial}{\partial x}\left(\lambda_x\frac{\partial\vartheta}{\partial x}\right) + \frac{\partial}{\partial z}\left(\lambda_z\frac{\partial\vartheta}{\partial z}\right)\right] = -\frac{\vartheta}{\rho}\frac{\partial\rho}{\partial\vartheta}\left(\frac{\partial p}{\partial t} + u\frac{\partial p}{\partial x}\right) + \eta\left(\frac{\partial u}{\partial z}\right)^2$$

$$\rho_{1,2}c_{p,1,2}\left(\frac{\partial\vartheta}{\partial t} + v_{1,2}\frac{\partial\vartheta}{\partial x}\right) - \left[\left(\lambda_{1,2}\frac{\partial^2\vartheta}{\partial x^2}\right) + \left(\lambda_{1,2}\frac{\partial^2\vartheta}{\partial z^2}\right)\right] = 0$$





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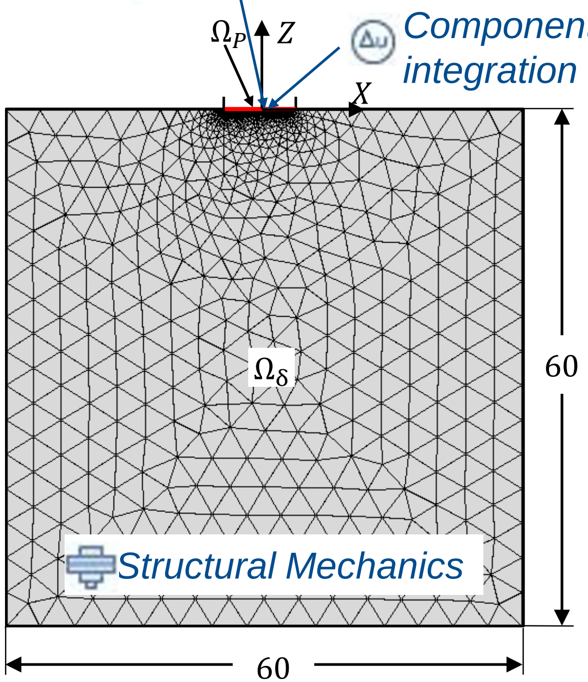
Model Implementation COMSOL

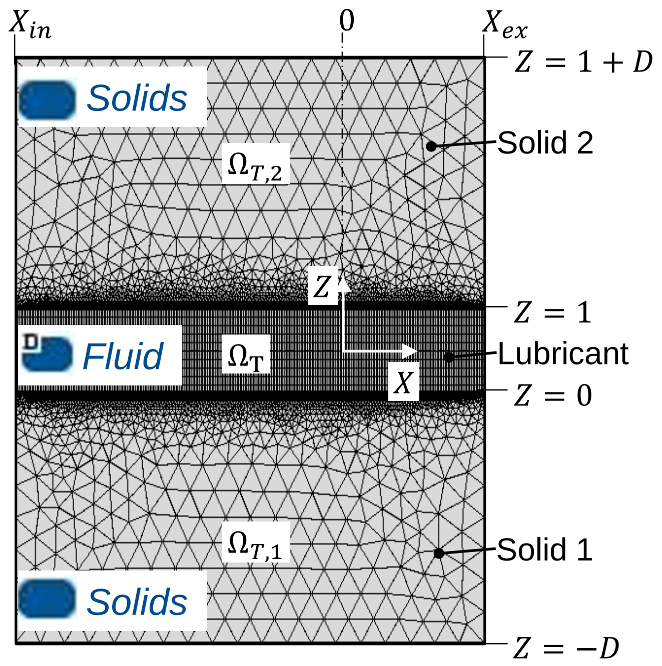
FEM-model(P, H)

Weak Form Boundary PDE



FEM-model($\overline{T}$)

Heat Transfer in Fluids



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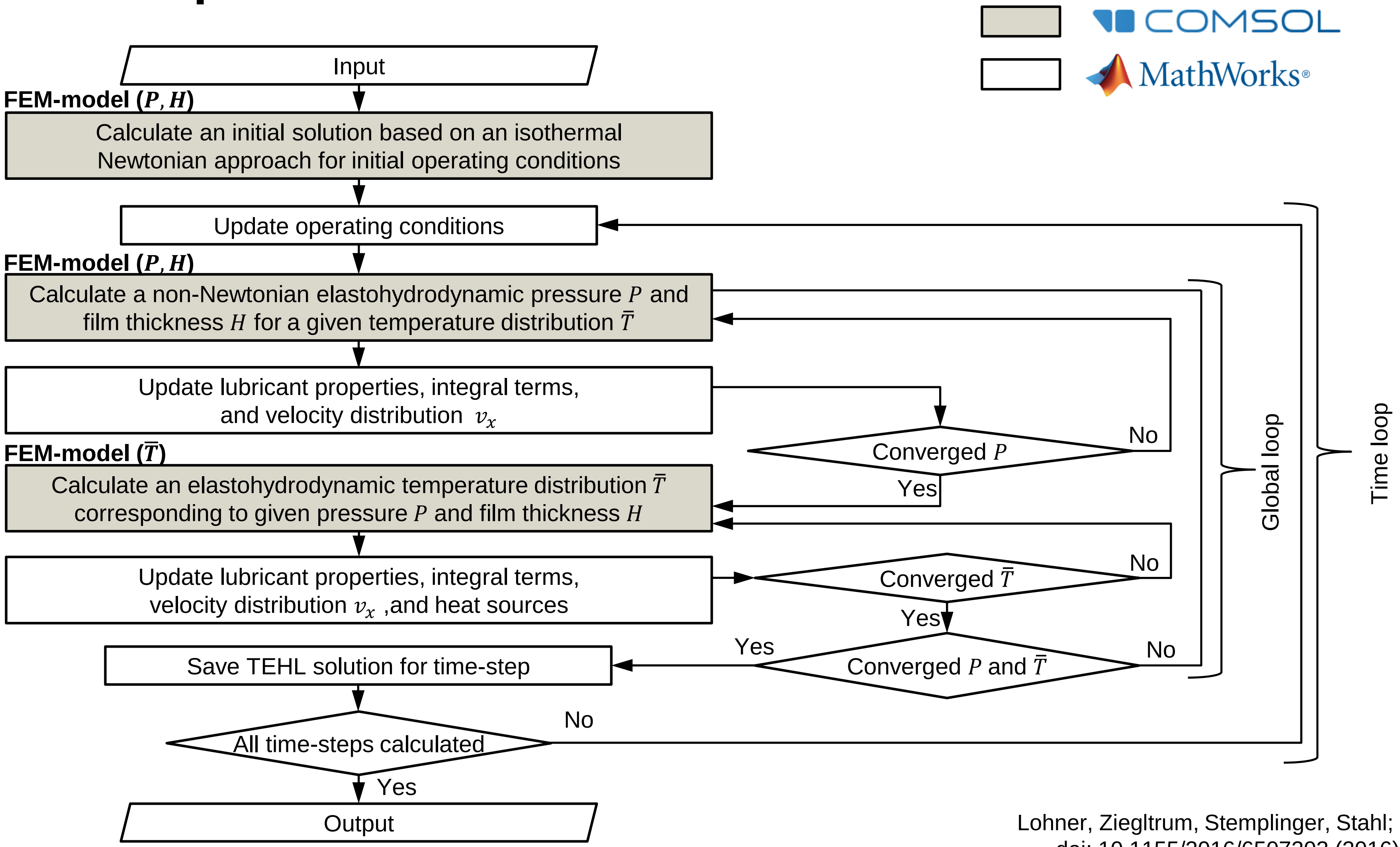
Model Implementation



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Exemplarily Results

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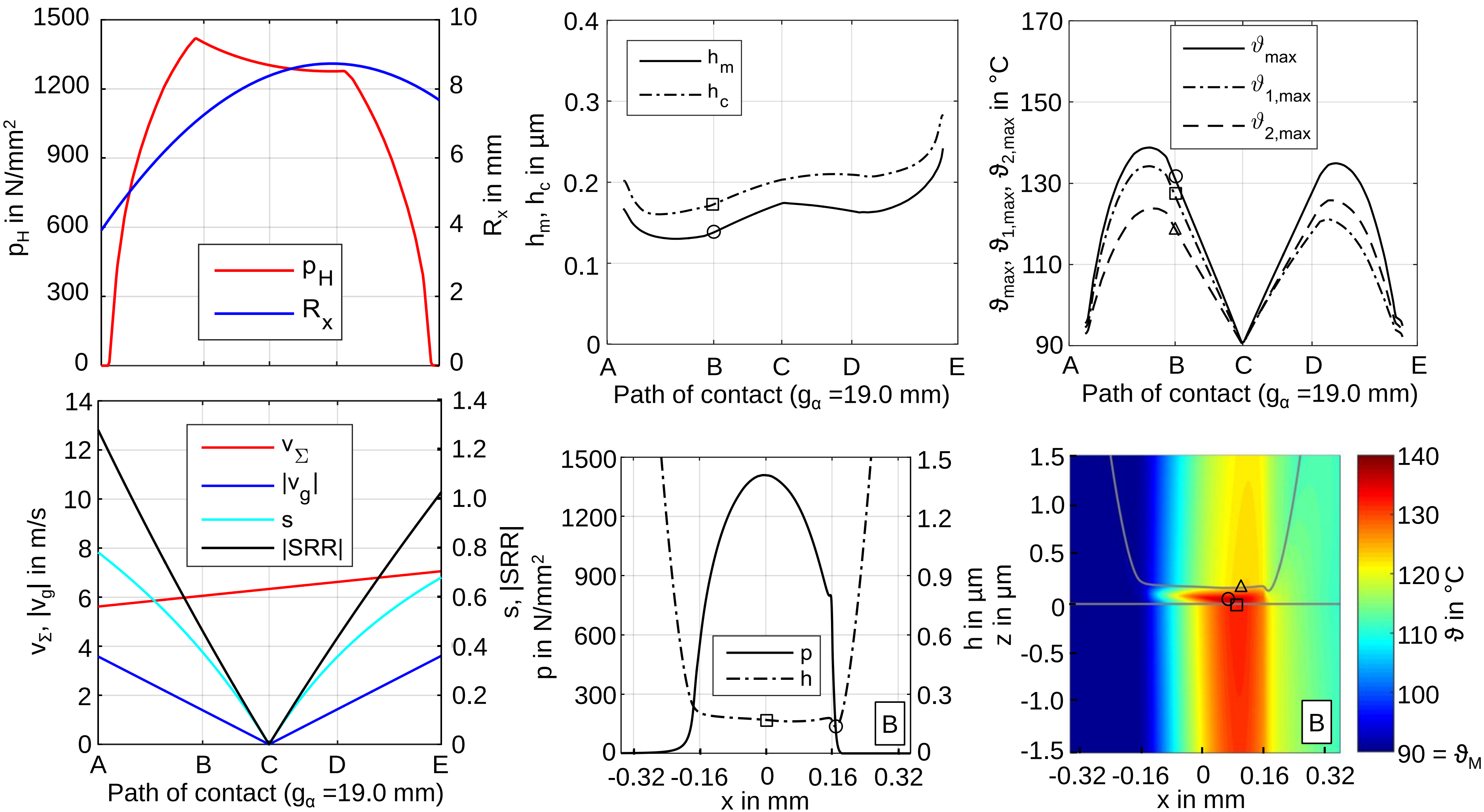

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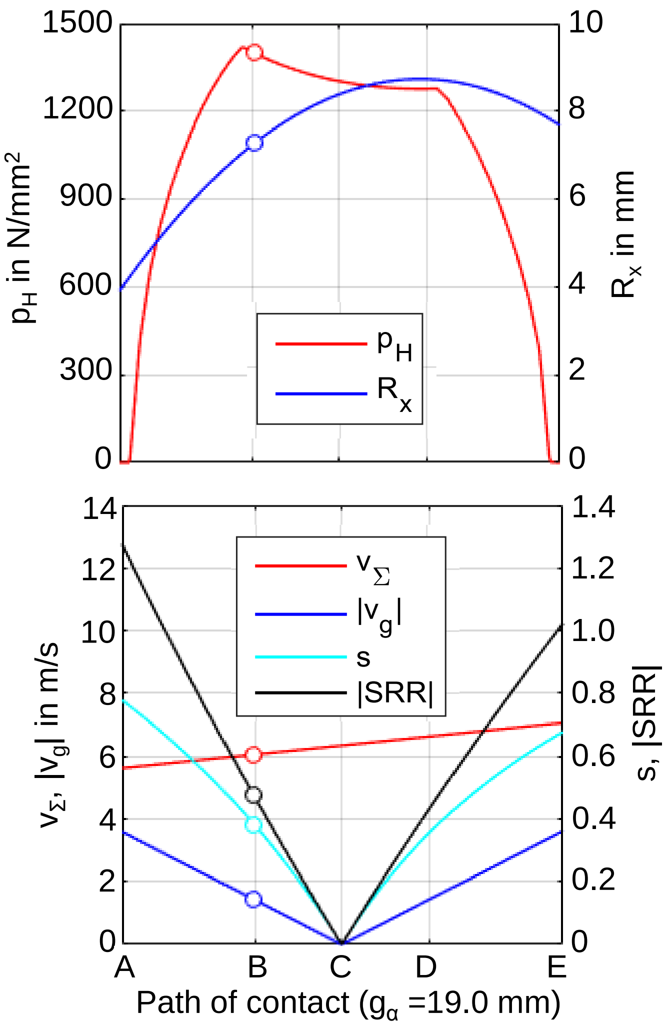

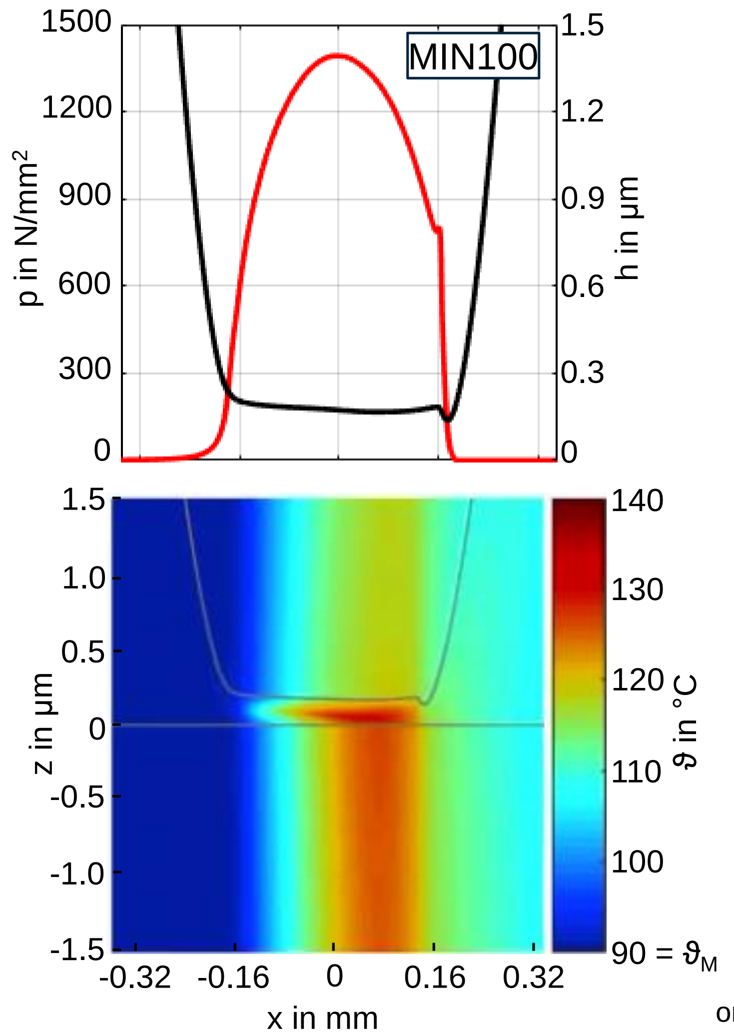

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Conclusion

- Simulation model for transient TEHL contacts considering non-Newtonian fluid behavior and thermal contact conditions has been developed
- Numerical procedure is based on a direct FEM-based full-system approach and iteratively coupled to the thermal problem
- Simulation model has been implemented in COMSOL Multiphysics and applied to the transient TEHL contact along the path of contact of spur gears
- Further modelling will be focused on rough gear surfaces and mixed lubrication regime