# Piston Slippers for Robust Water Hydraulic Pumps

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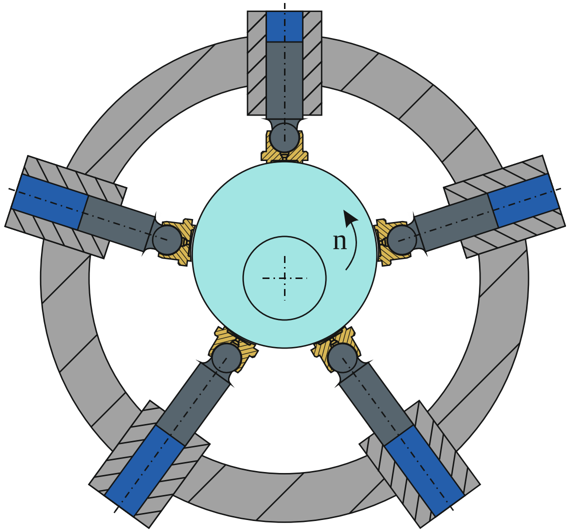
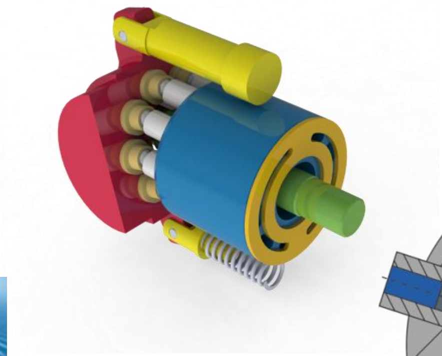


# Motivation

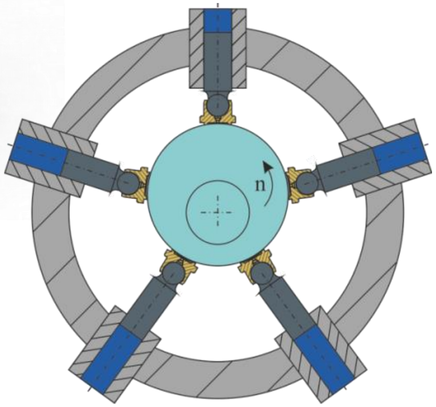
## Water Hydraulics

| Applications | Advantages | Challenges |
|---|---|---|
| ▪ Food industries<br>▪ Pharmaceutic industries<br>▪ Mining<br>▪ Descaling | ▪ Not flammable<br>▪ Not toxic<br>▪ Good availability of tap water | ▪ Low viscosity<br>▪ Poor lubrication<br>▪ Different materials<br>▪ Complex components |

- Plunger pumps

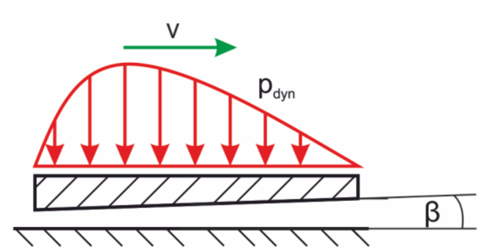



- Axial piston pumps
- Radial piston pumps



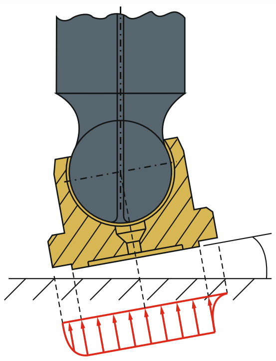
# Research at IFAS

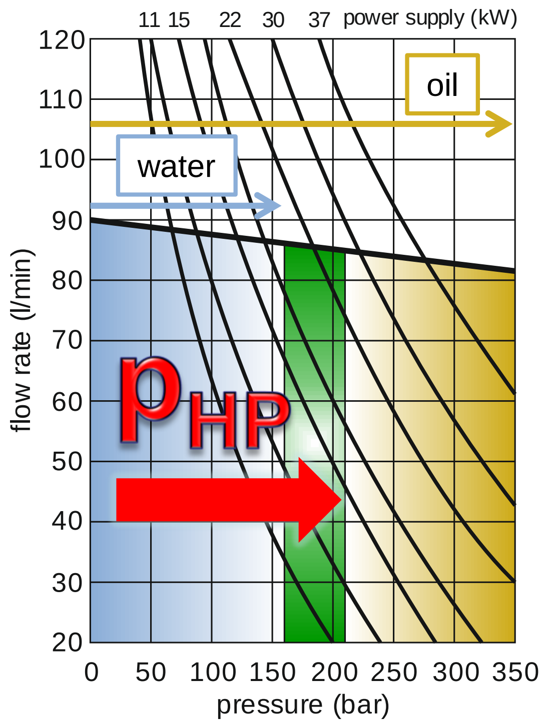
- Development of water hydraulic radial piston pump
  - Tap water as pressure medium
  - Water lubrication
  - Pressure level > 160 bar
  
  → Increased power density




- Tribological contacts
  - Load carrying capacity
  - Leakage, wear

- Simulation development
- Comparison of piston slippers
  - Axial piston pump
  - Radial piston pump





1 Introduction

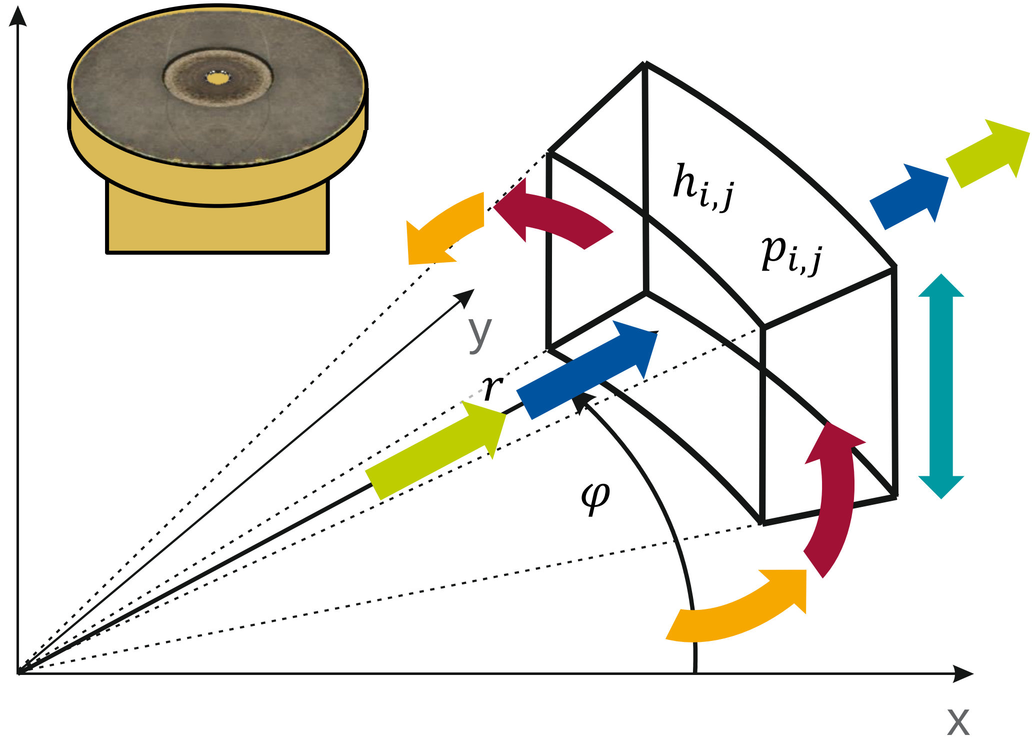
2 Simulation Model and Results

3 Effect of Slipper Deformation

4 Conclusion and Outlook

# Reynold-Equation in Polar Coordinate System

- Reynolds-Equation
  - **Newtonian fluid**
  - **Incompressible fluid**
  - Laminar flow with Re << 1
- Polar coordinate system
  - Fluid film under slipper pad
  - → Plate geometry
- Modeling
  - Fluid film pressure
  - No contact pressure model
  - No model of surface roughness




$$\frac{\partial}{\partial r}\left(r \cdot \frac{h^3}{12 \cdot \mu} \cdot \frac{\partial p}{\partial r}\right) + \frac{\partial}{\partial \varphi}\left(\frac{h^3}{12 \cdot \mu} \cdot \frac{1}{r} \cdot \frac{\partial p}{\partial \varphi}\right) - \frac{u_r}{2} \cdot r \cdot \frac{\partial h}{\partial r} - \frac{u_\varphi}{2} \cdot \frac{\partial h}{\partial \varphi} = \frac{\partial h}{\partial t} = 0$$

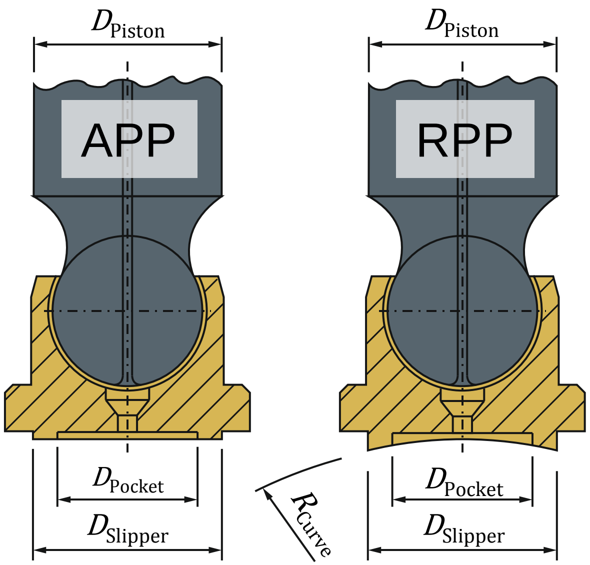
# Comparison of Piston Slippers

<u>Slipper geometry</u>

- Axial piston pump (APP)
- Radial piston pump (RPP)

$\Delta R = R_{Curve} - R_{Ecc}$

- 10 µm
- 20 µm




- Calculation of hydrostatic compensation
  → Load carrying capacity
- Leakage

$$q_{C,eff} = \frac{F_{Fluid}}{F_{Piston}} = \frac{\int p_{(r,\varphi)} \cdot dA}{p_{HP} \cdot D_{Piston}^2 \cdot \frac{\pi}{4}}$$

$$Q_{Leakage} = Q_p + Q_v \Big|_{r=D_{Pocket}/2}$$

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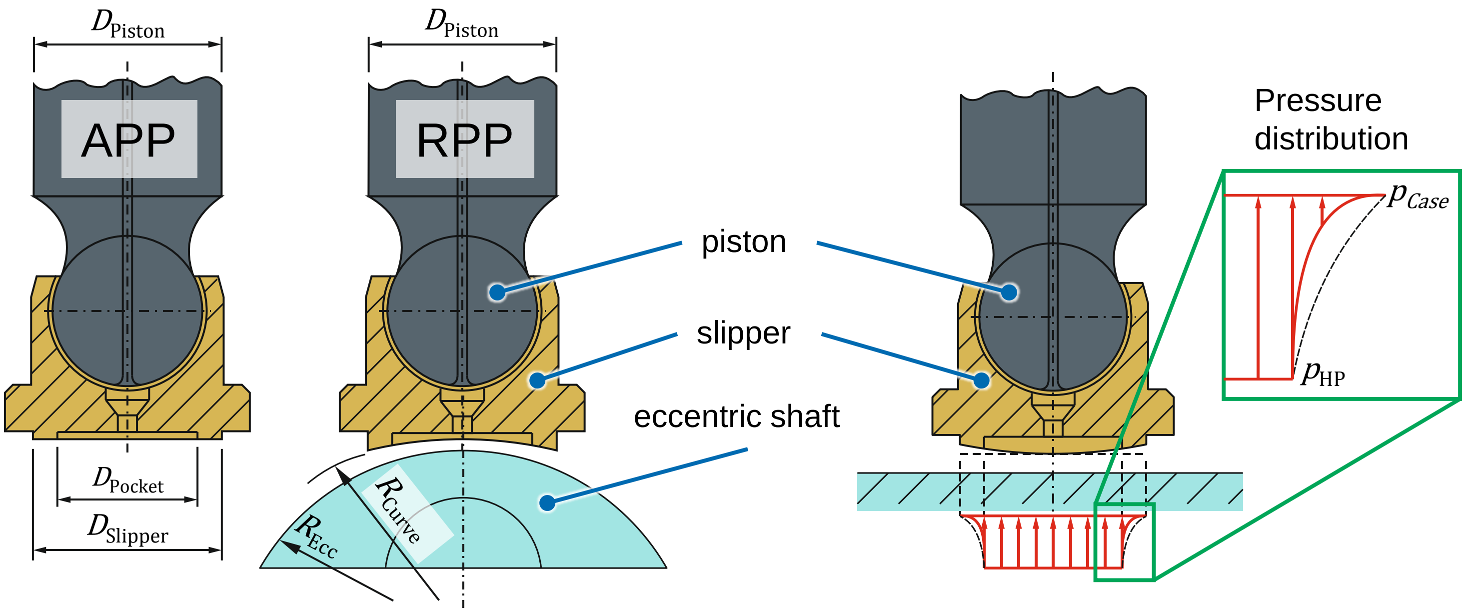


# Dynamic Pressure Build-Up during Motion

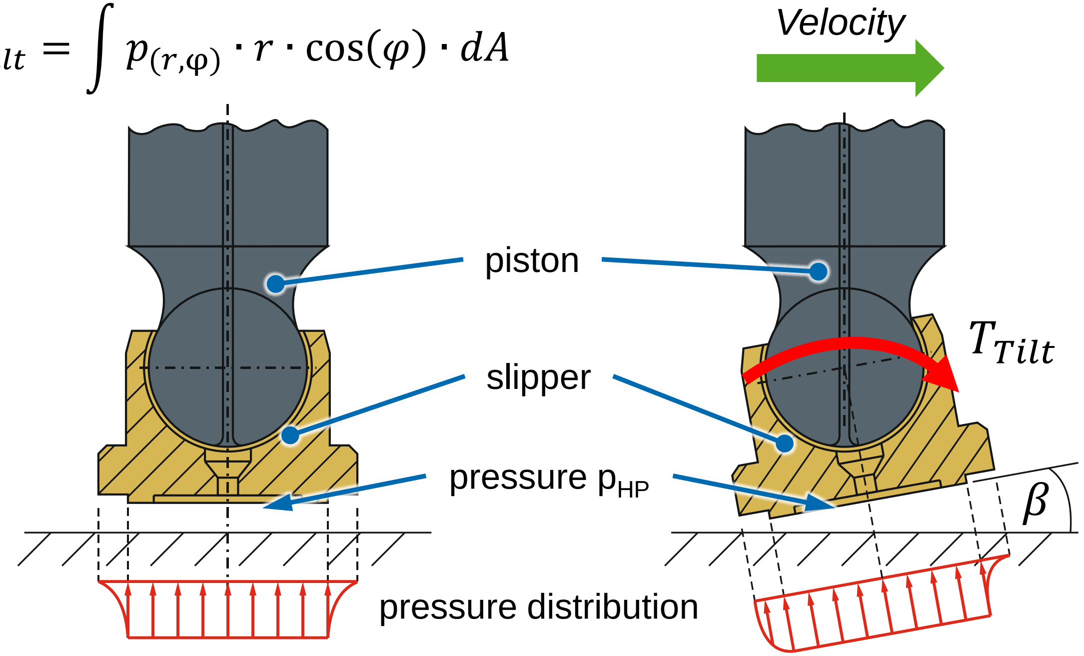
- Calculation of dynamic pressure build-up
  - Lateral movement of piston-slipper-assembly
  - Slipper is tilted against plane surface
- Hydrodynamic compensation
- Leakage
- Additional tilting torque $T_{Tilt} = \int p_{(r,\varphi)} \cdot r \cdot \cos(\varphi) \cdot dA$

$$q_{C,eff} = \frac{F_{Fluid}}{F_{Piston}} = \frac{\int p_{(r,\varphi)} \cdot dA}{p_{HP} \cdot D_{Piston}^2 \cdot \frac{\pi}{4}}$$

$$Q_{Leakage} = Q_p + Q_v\Big|_{r=D_{Pocket}/2}$$

MATLAB

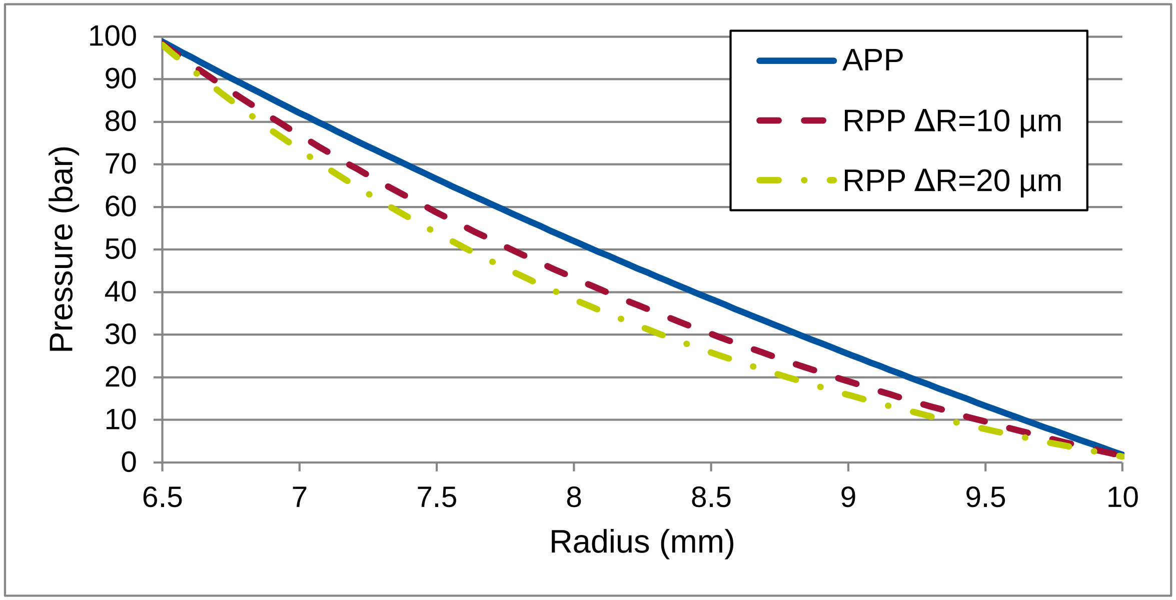
| Simulation parameter | |
|---|---|
| Gap height: | 0.5 µm |
| Angle $\beta$: | 0.001° |
| Pressure: | 100 bar |
| Velocity: | 1 m/s |



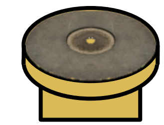
# Results

Static, no motion

| | APP | RPP $\Delta R$ = 10 µm | RPP $\Delta R$ = 20 µm |
|---|---|---|---|
| $q_{C,eff}$ | 93.2 % | 91.6 % | 89.8 % |
| $Q_{Leakage}$ | 100 % (0.088 ml/min) | 176 % (0.155 ml/min) | 300 % (0.264 ml/min) |



# Results



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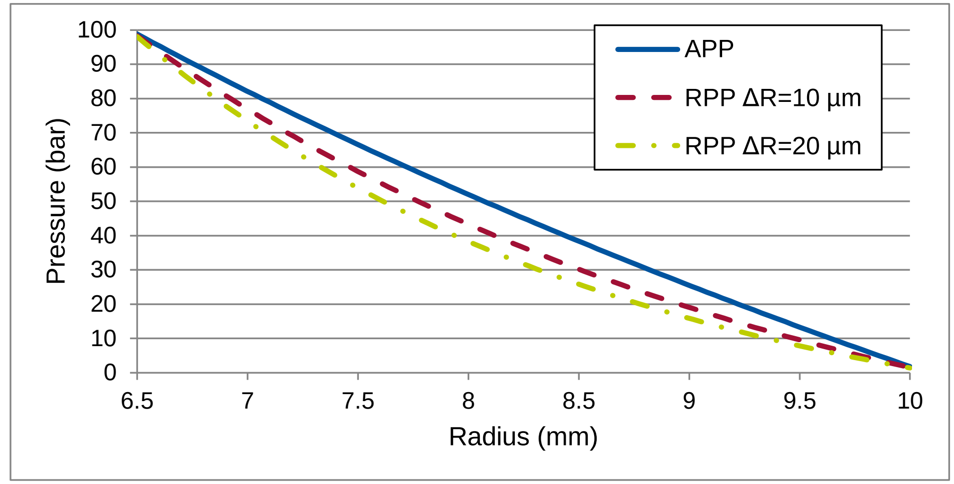
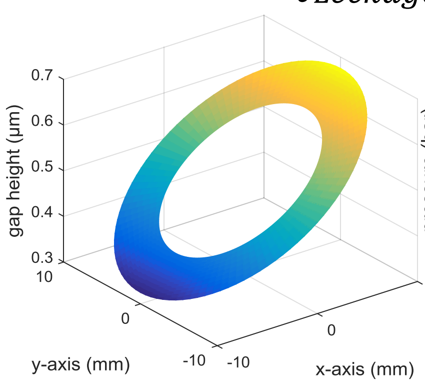
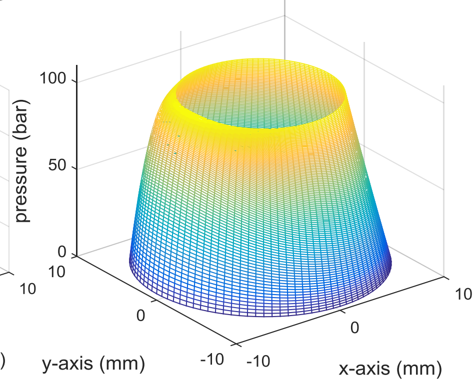



## Dynamic

**APM**

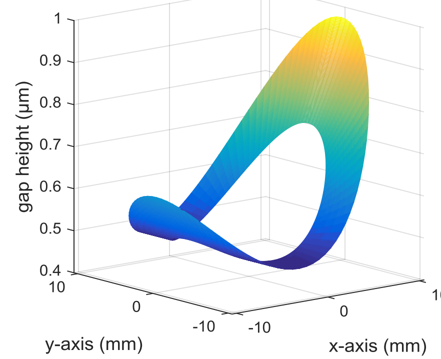
$q_{C,eff}$ = 94.2 %
$Q_{Leckage}$ = 0.617 ml/min

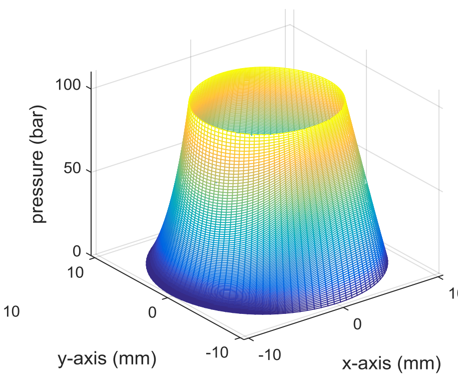



**RPM**

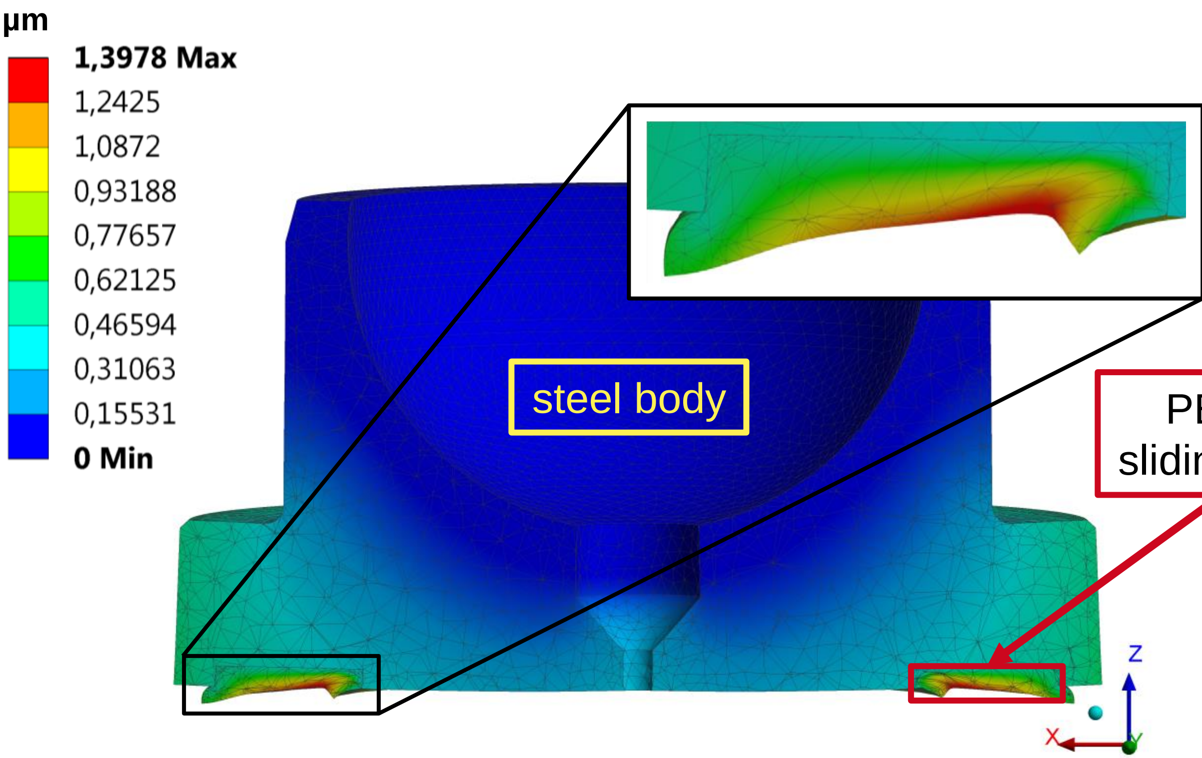
$q_{C,eff}$ = 93.3 %
$Q_{Leckage}$ = 0.837 ml/min



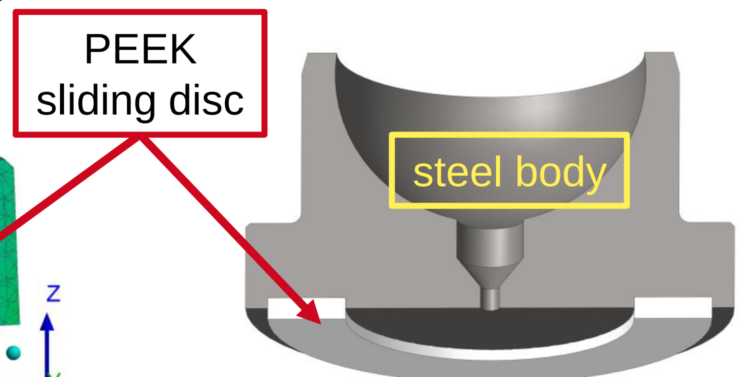



# Deformation of Slipper

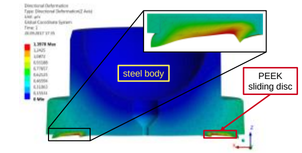
- Effects of using plastic materials
  - Deformation of materials under pressure load
  - Altered gap height distribution
  - Increased leakage due to enlarged gap height



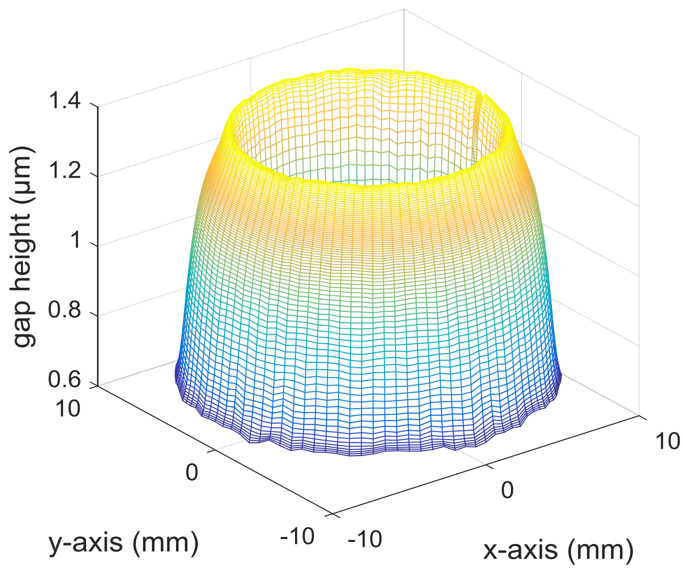

- Simulation
  - Deformation in Ansys
  - Matlab-Code for Reynolds-Equation



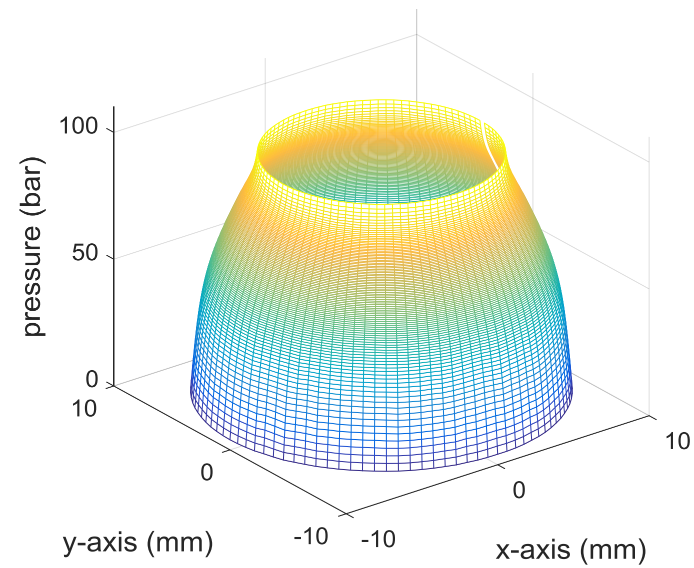
# Results




## Gap height




## Pressure distribution

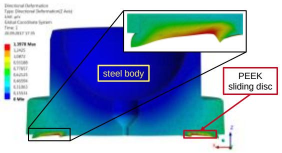



- Increased load carrying capacity due to over compensation
- Leakage increased by factor 5 compared to undeformed result

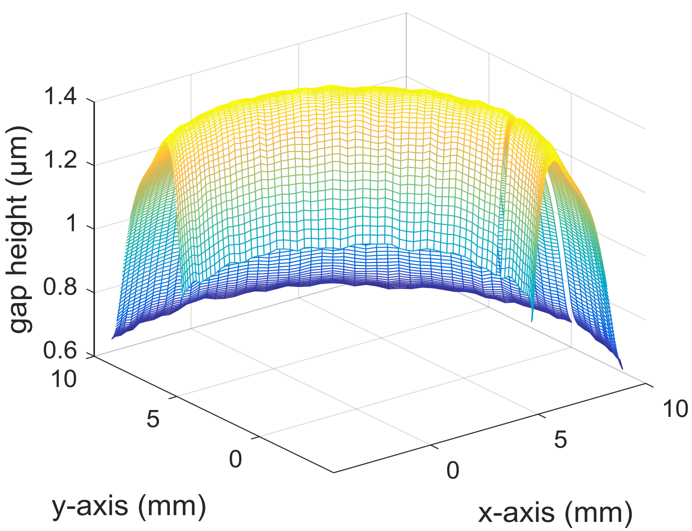
**Simulation results**

- $q_{C,eff}$ = 106.7 %
- $Q_{Leakage}$ = 0.81 ml/min

# Results

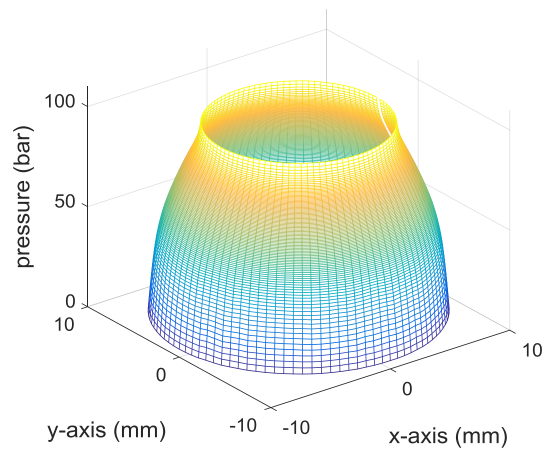



## Gap height

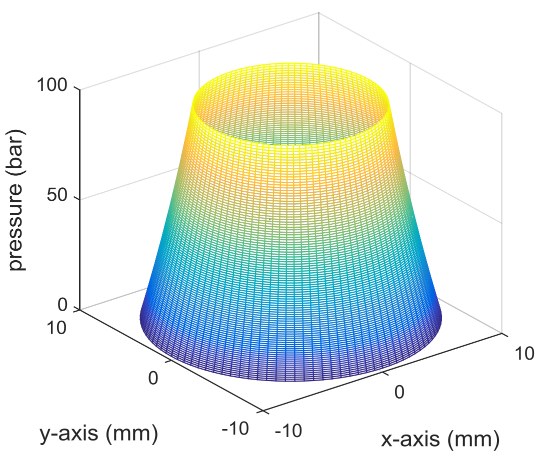



## Pressure distribution

Deformed




Undeformed

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**Simulation results**

- $q_{C,eff}$ = 106.7 %
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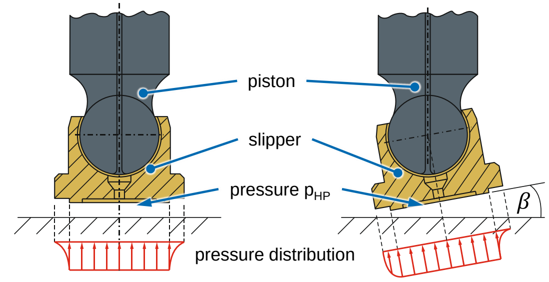
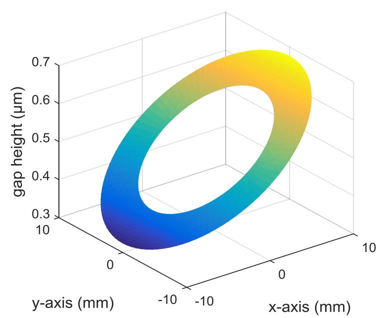
# Conclusion and Outlook

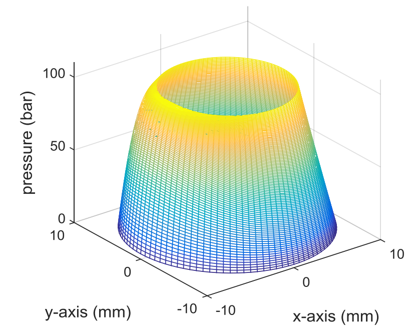
- Simulation of piston slippers

- Radial piston pump
  - Effect of manufacturing tolerances
  
  → Lower load carrying capacity

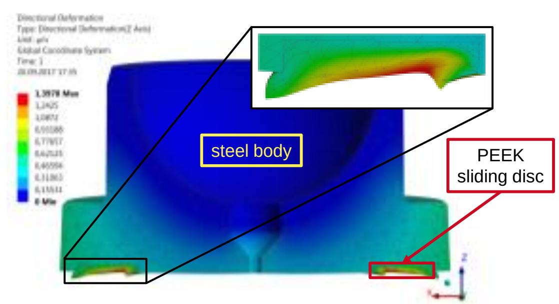



- Deformation of plastic slippers
  - Same magnitude as gap height
  - Overcompensation
  - Increased leakage




- Maximum pressure level for water hydraulics
- Development water hydraulic radial piston pump



# Thank you for your attention!

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