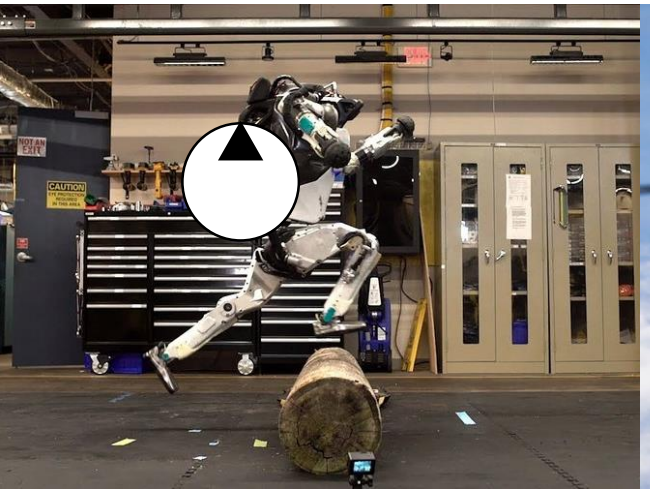
Modeling, Improving, and Scaling of Lubricating Interfaces in Axial Piston Machines

June 4nd, 2019

Lizhi Shang

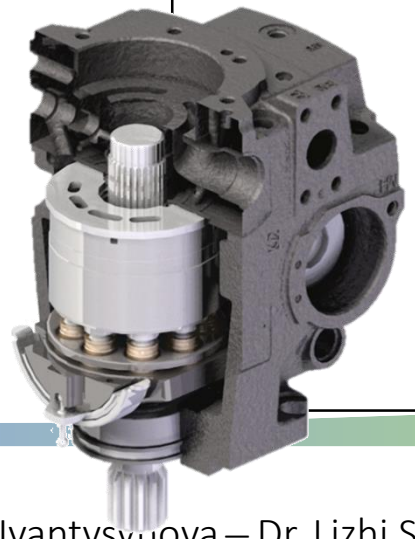
Post doctoral research assistant
Maha Fluid Power Research Center
Purdue University

Swashplate type axial piston machine applications



Axial piston pumps and motors

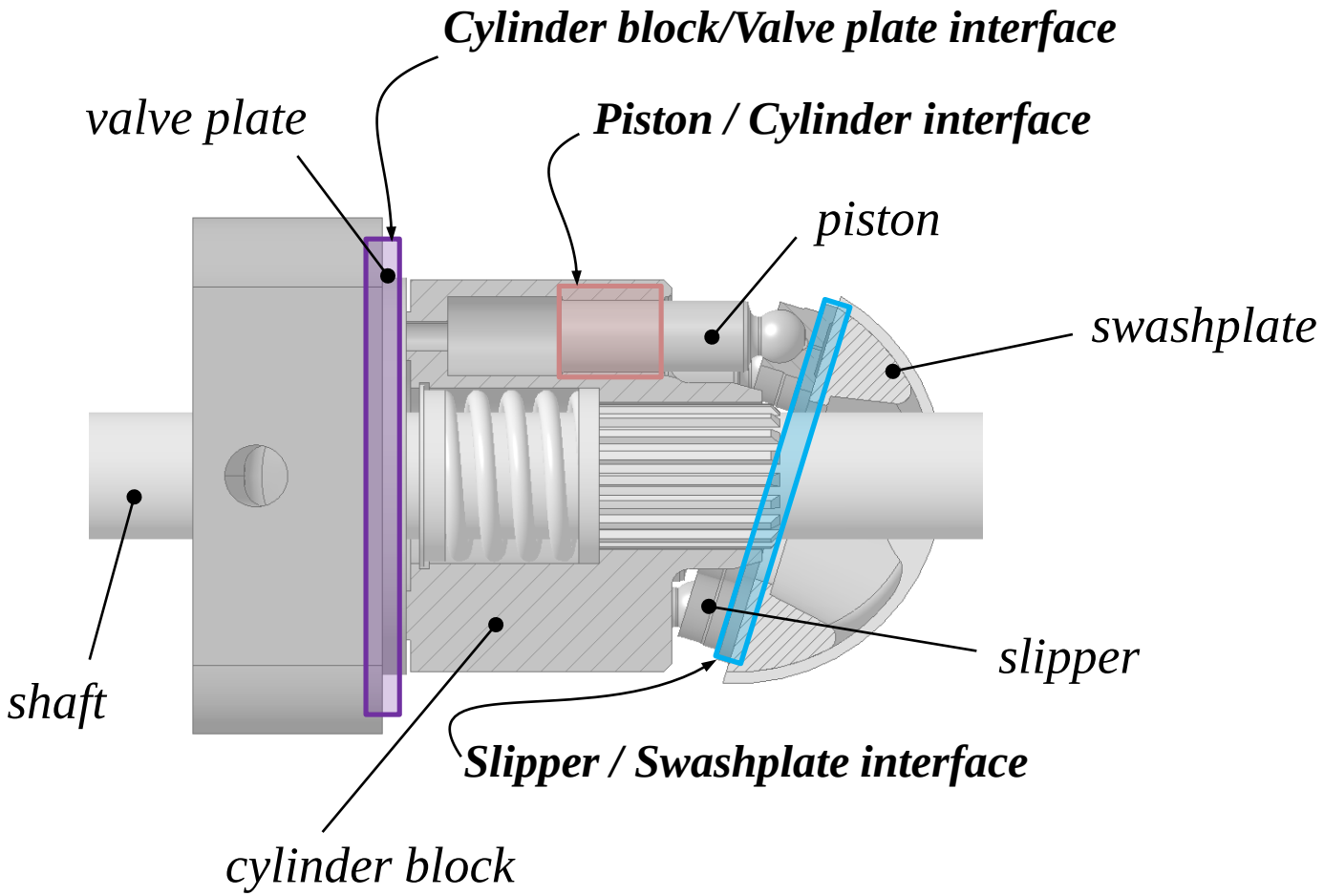
- High operating pressure
- Variable displacement
- High power density
- High efficiency

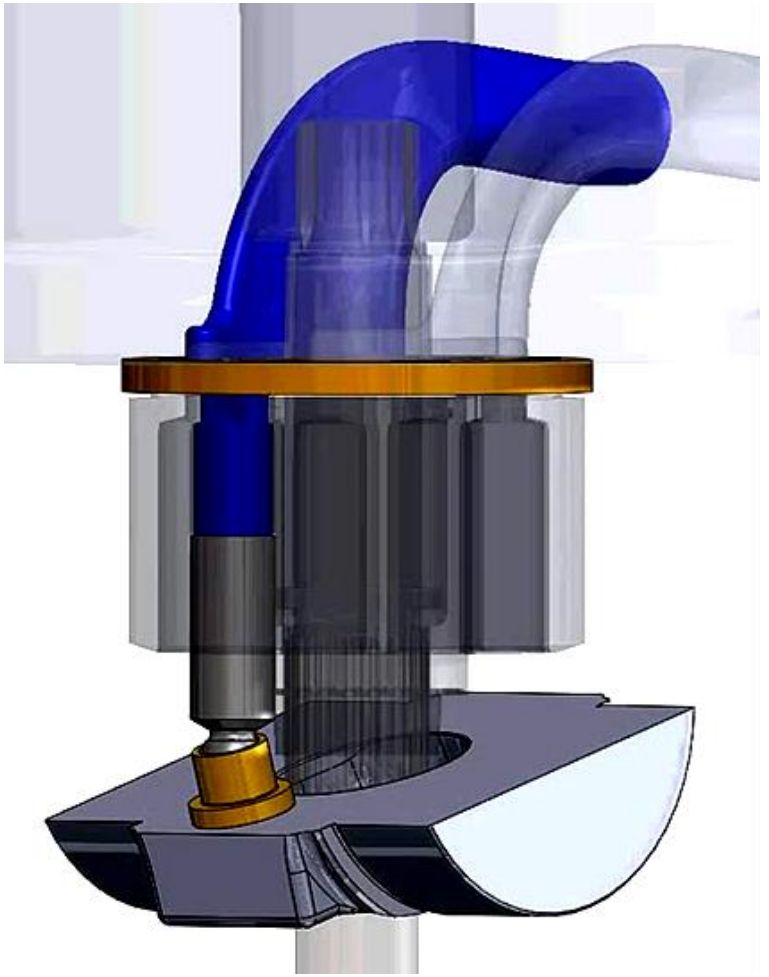


0.5cc

1000cc

Swashplate type axial piston machine

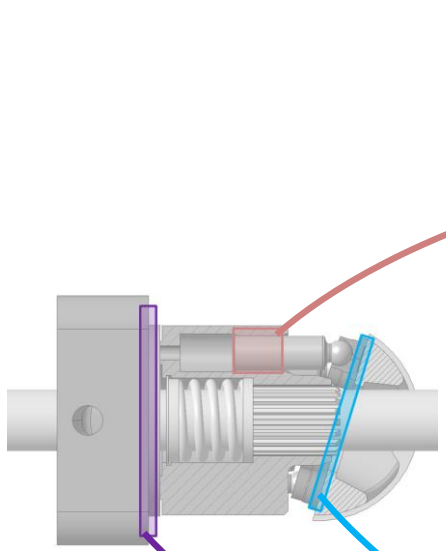


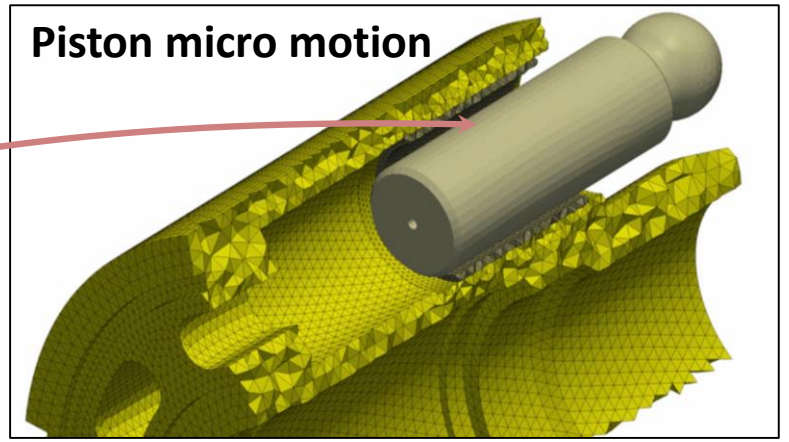


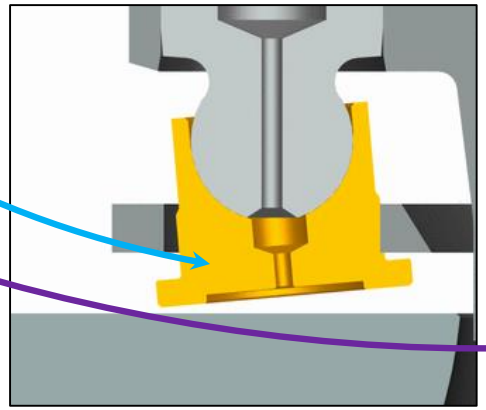
Videos from Schenk, A.

Challenge of lubricating interfaces design

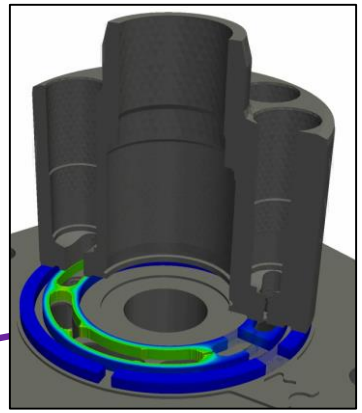
Complicated interactive physical phenomena







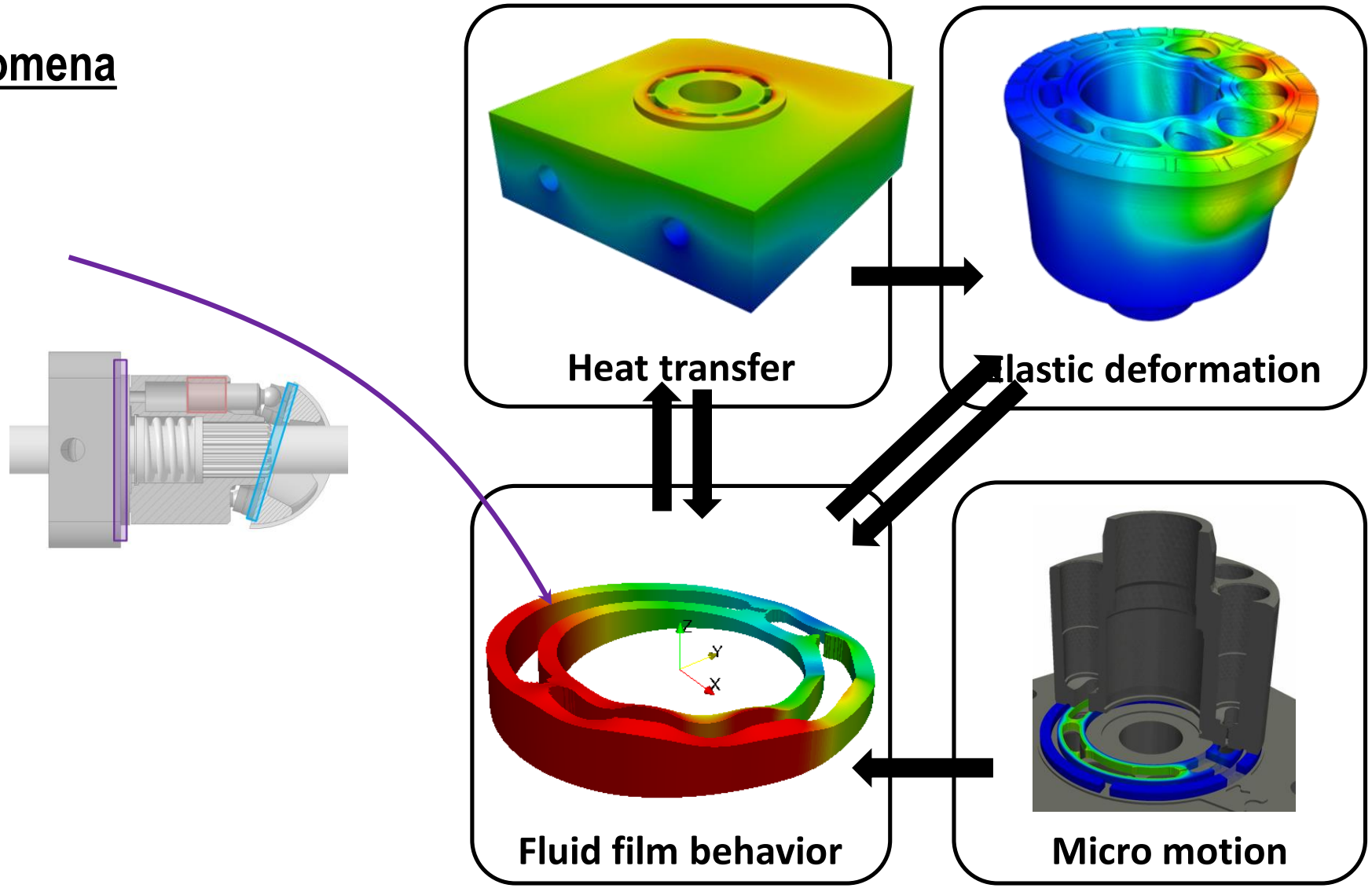
Slipper micro motion



Block micro motion

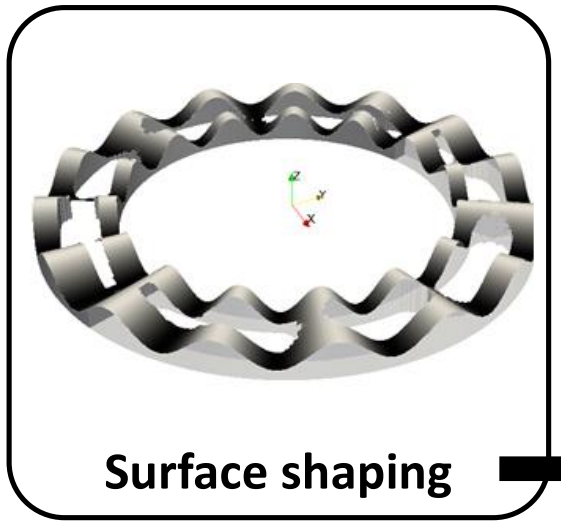
Challenge of lubricating interfaces design

Interactive physical phenomena

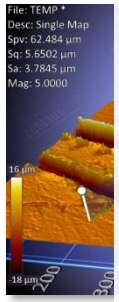


Videos from Zecchi, M.

Challenge of lubricating interfaces design



Surface shaping



Su

Measured by Keller, N.

- **Lubricating interfaces are difficult to design**, due to the **interactive physical phenomena** including:
  - Macro and micro motion
  - Fluid hydrostatic and hydrodynamic effects
  - Viscous shear and energy dissipation
  - Heat transfer
  - Elastic deformation
  - Surface texture and Surface shaping

Surface texture

Heat transfer

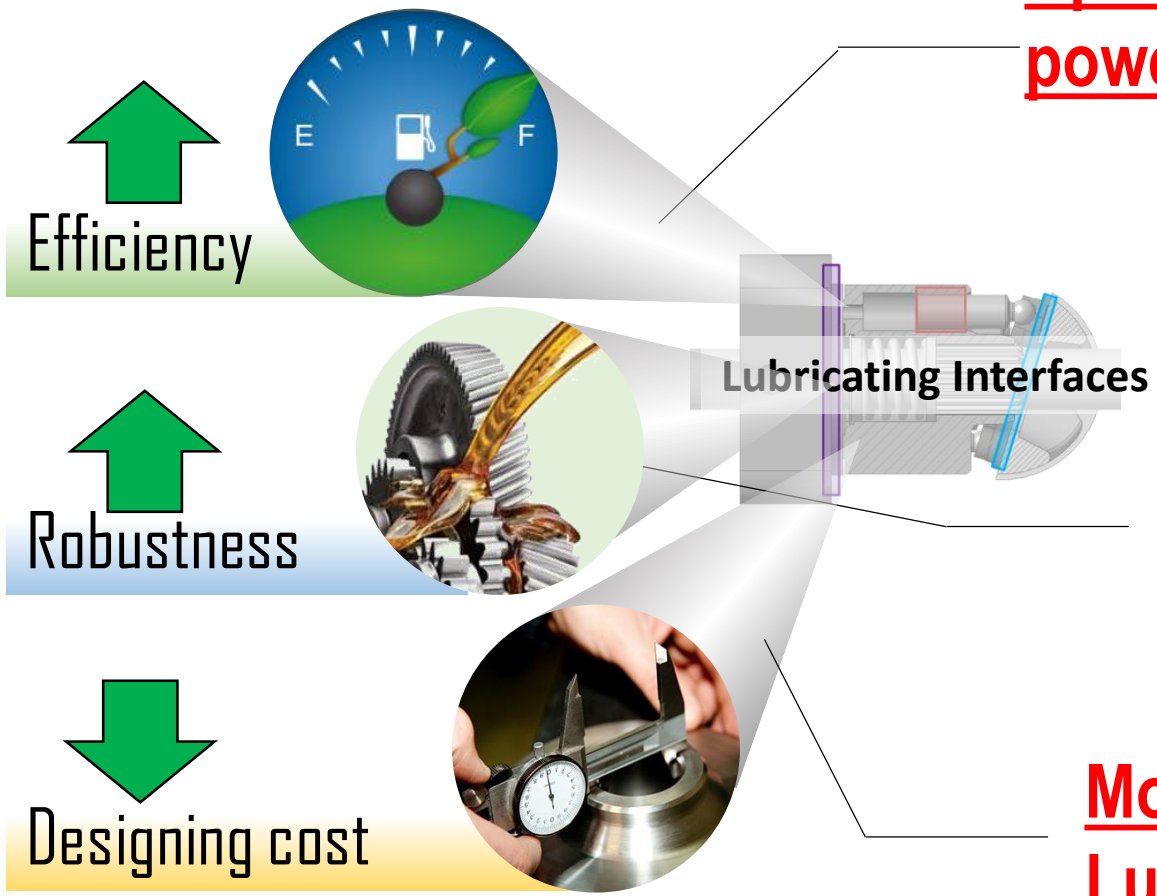
Elastic deformation

Fluid film behavior

Micro motion

Videos from Zecchi, M.

Swashplate type axial piston machine

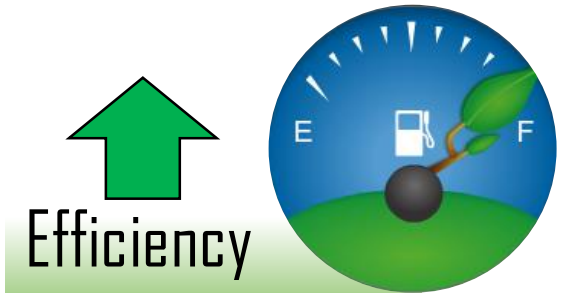


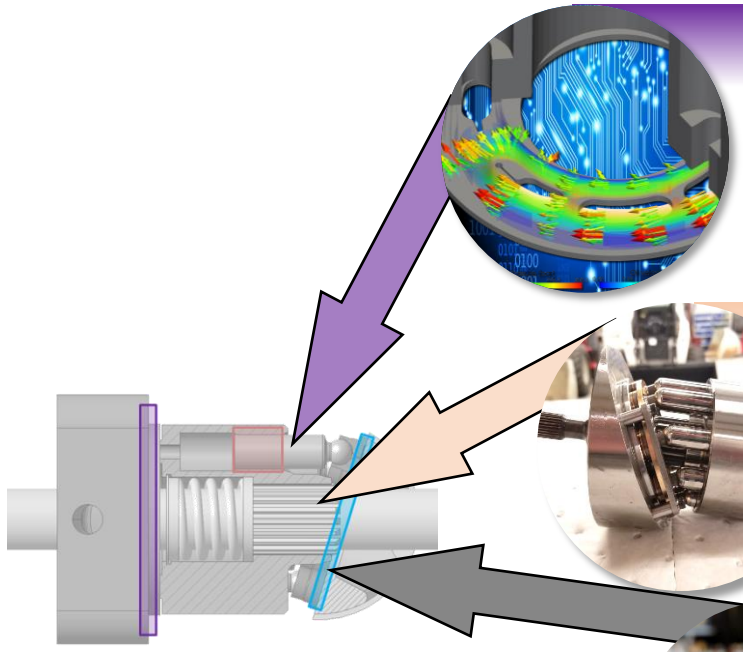
Up to 50% contribution to FP system power loss

Main contributor to pump and motor failure

More than 80% design effort on Lubricating interfaces

Research Topics





Modeling

- **Essential insight of lubricating interface behavior**

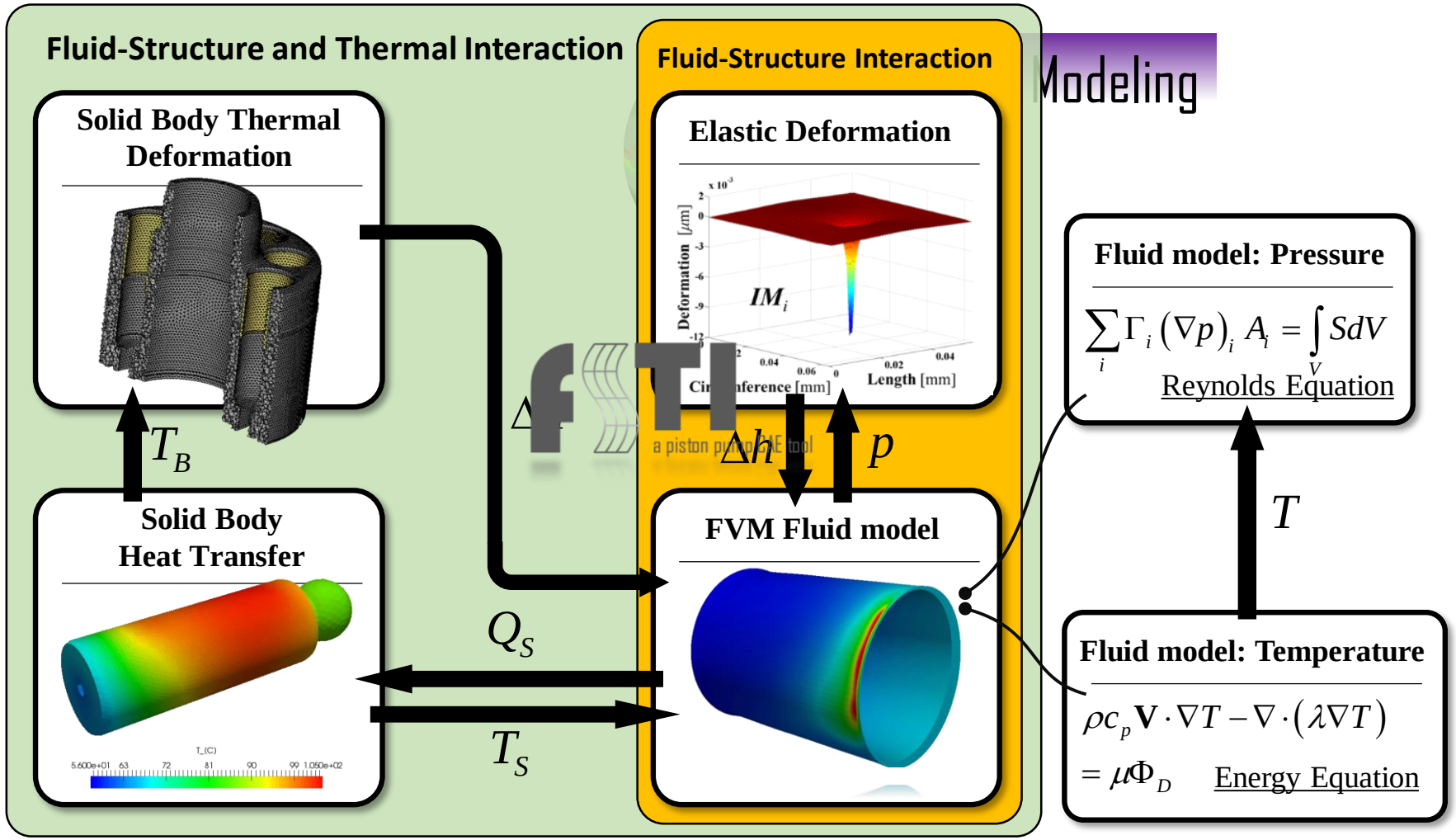
Improving

- **Efficient and Robust design**
- **Designing process**

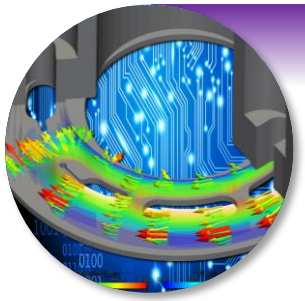
Scaling

- **Is lubricating interface scalable**
  - ❑ **No, why not**
  - ❑ **Yes, How**

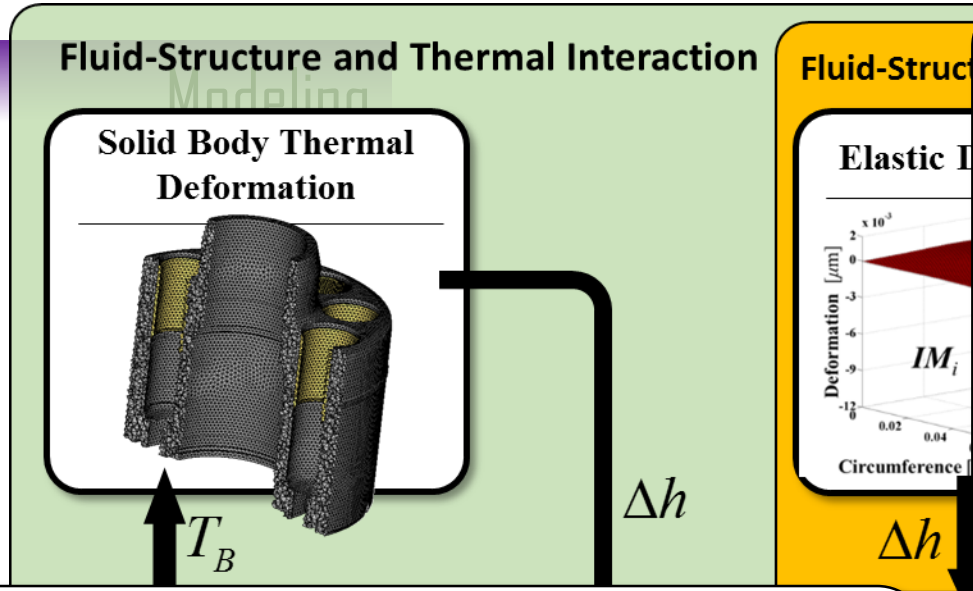
Axial piston machine modeling approach



Axial piston machine modeling approach



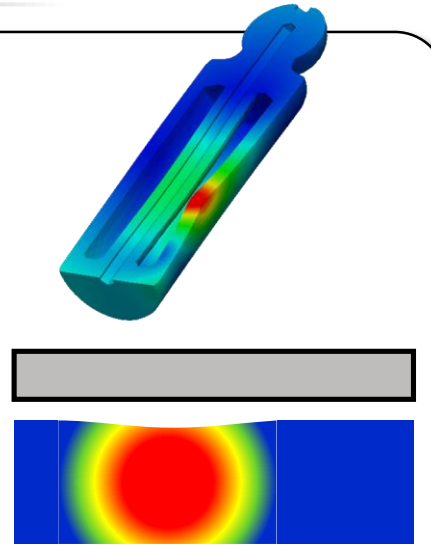
FSTI a piston pump CAE tool



Pressure solver overhaul

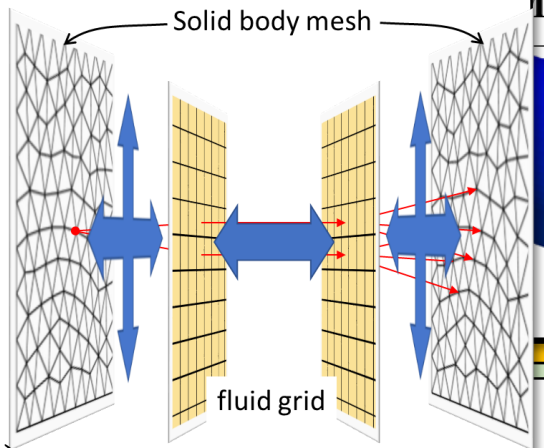
- ➢ Validated load carrying capability prediction.
- ➢ Robust and accurate scheme for low film thickness and contact region.

Shang, L. (2018 dissertation)



Integrated heat transfer model

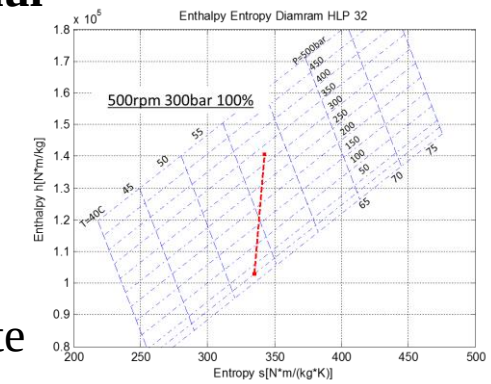
- Robust scheme allows for extreme operating temperature
- Converge with less iteration



Shang, L., Ivantysynova, M. (2018)

Temperature solver overhaul

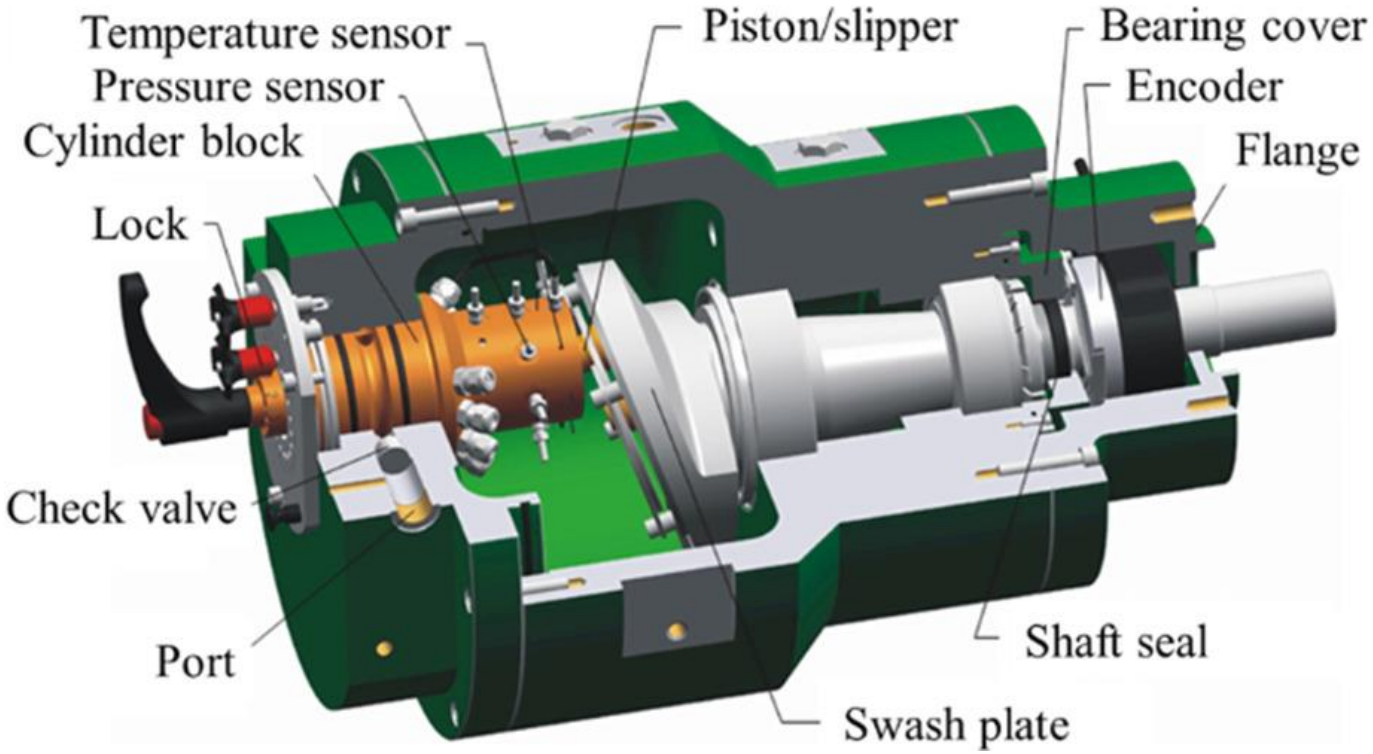
- Convection
- Conduction
- Energy dissipation
- ➢ Compression
- ➢ Expansion
- ➢ Temperature changing rate



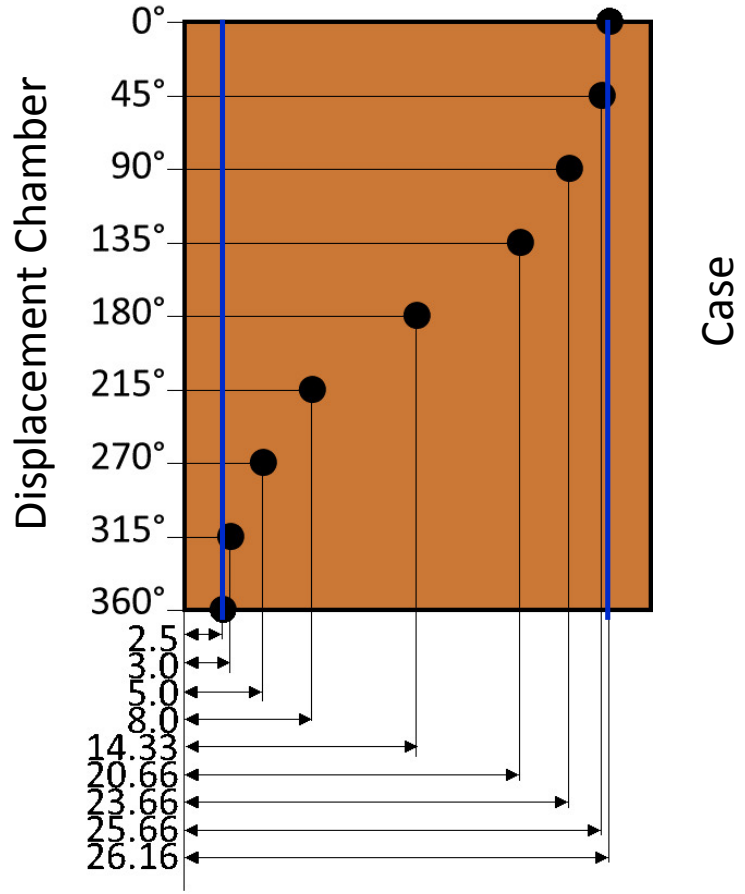
Shang, L., Ivantysynova, M. (2017)

Experimental validation

EHD test pump
Bushing surface temperature distribution measurement during operation

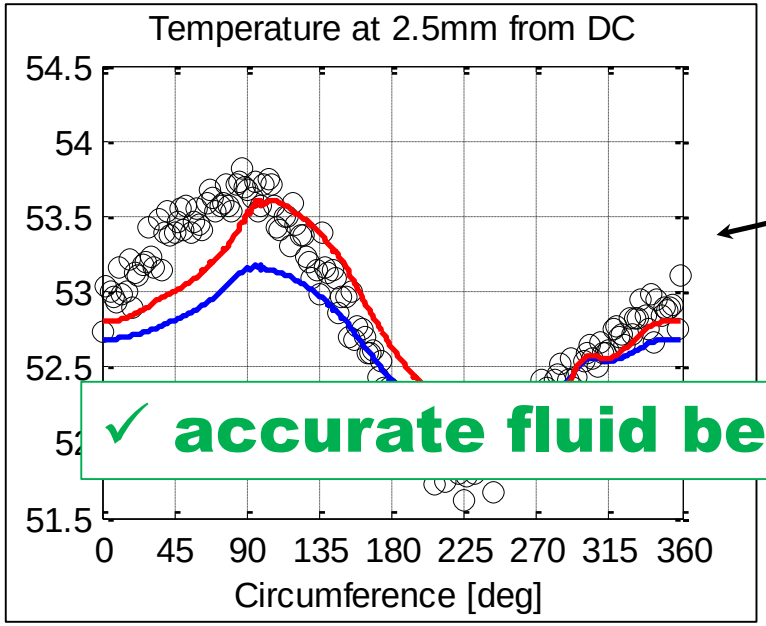


Everth, H. (2003)

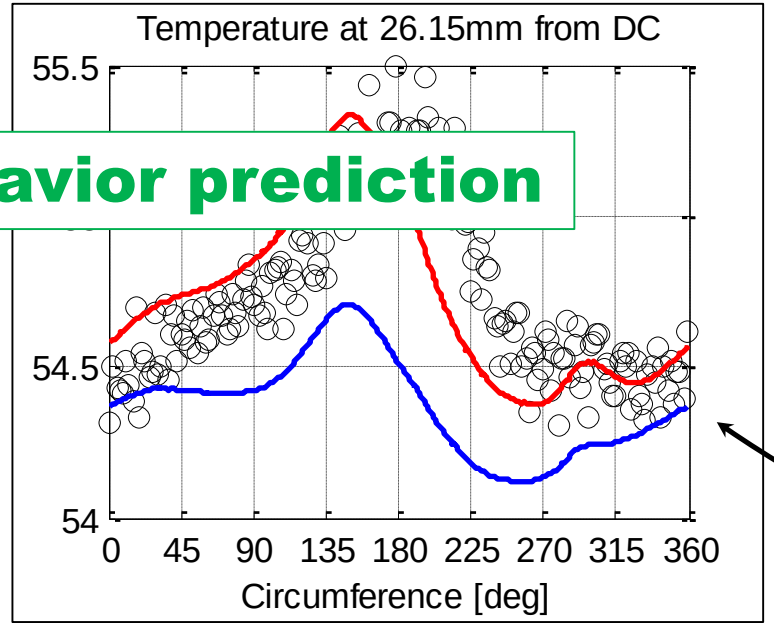


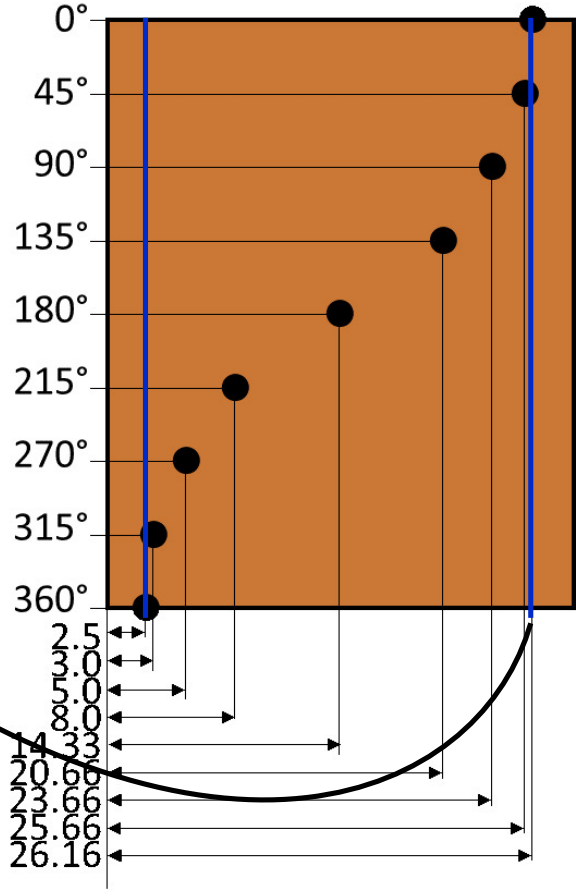
Experimental validation

EHD test pump
Bushing surface temperature distribution measurement during operation



✓ accurate fluid behavior prediction

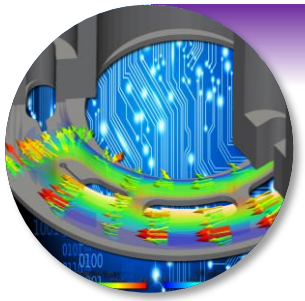




Measurement
Before temperature overhaul
After temperature overhaul

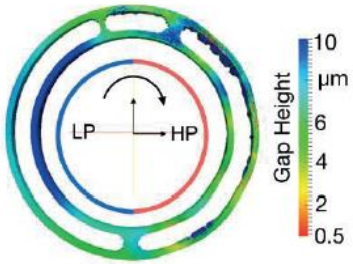
Shang, L (2018 dissertation)

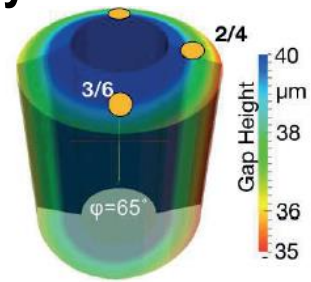
From modeling to innovation



Modeling

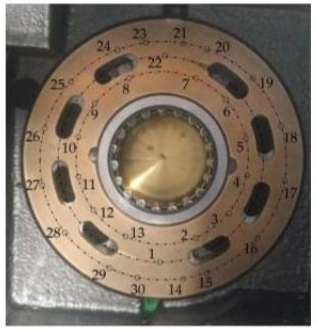
- **Pump lifetime study**

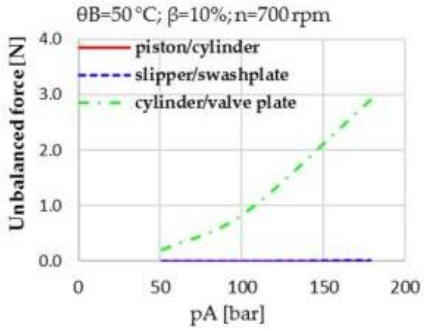




Ivantysyn, R., Weber, J. (2018)

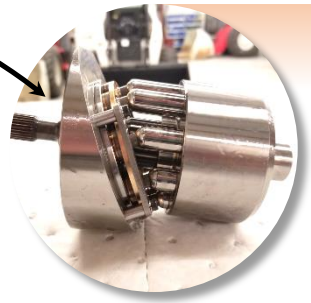
- **Pump design optimization**





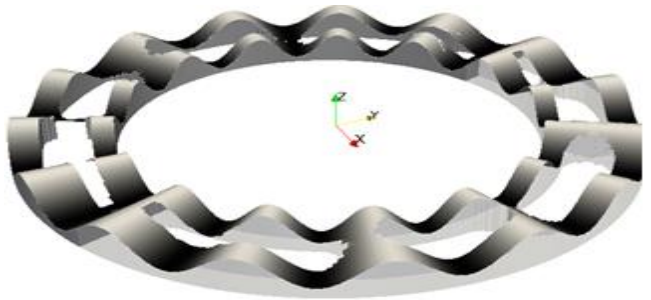
Chacon, R.. Ivantysynova, M. (2019)

Insight of lubricating interface behavior



Innovation

- **Micro shaping concept**



- **Virtual prototyping**

Scaling

- **Lubricating interfaces are difficult to design**
- **Wide range of demanded size**


> 2000 times in size


1. **Are lubricating interfaces linearly scalable?**
2. **Is there an effective scaling rule?**

Scalability of elastic deformation

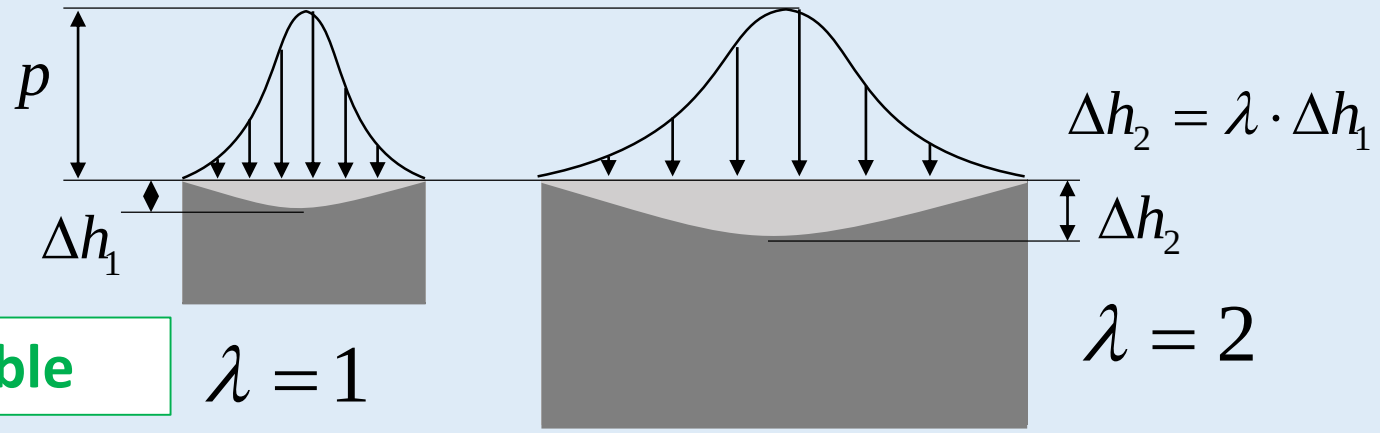
Linear scaling rule:

$$\lambda = \left(\frac{V}{V_0} \right)^{\frac{1}{3}}$$

$$h = \lambda \cdot h_0 \quad l = \lambda \cdot l_0$$

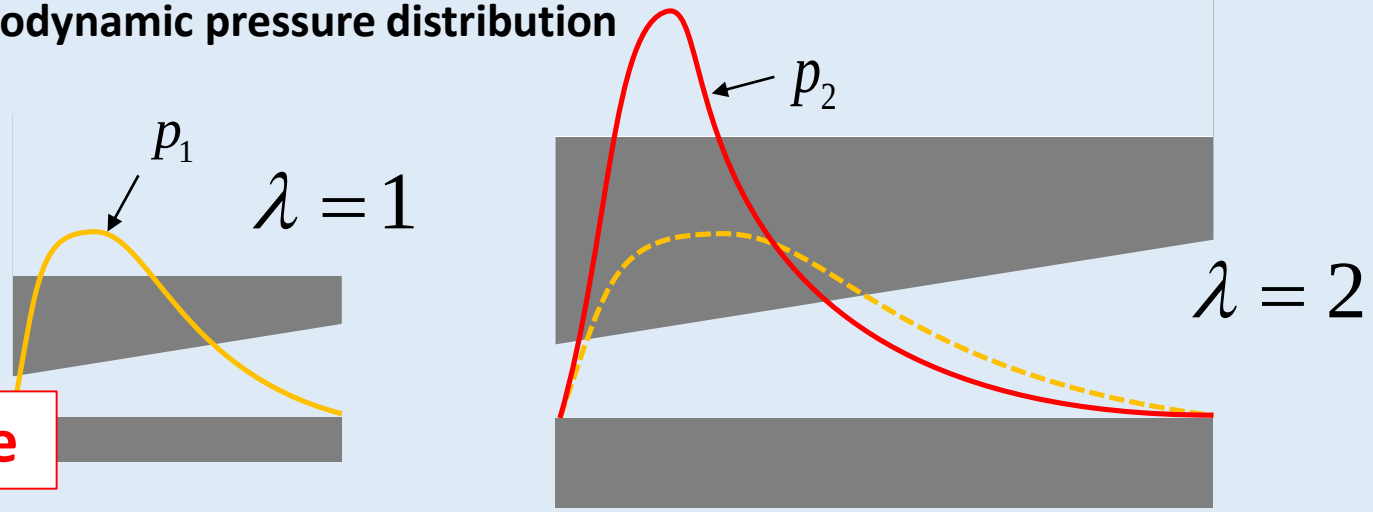
$$p = p_0 \quad T = T_0$$

Elastic deformation due to thermal and pressure load



scalable

Hydrostatic/hydrodynamic pressure distribution



Not scalable

Scalability of fluid domain heat transfer

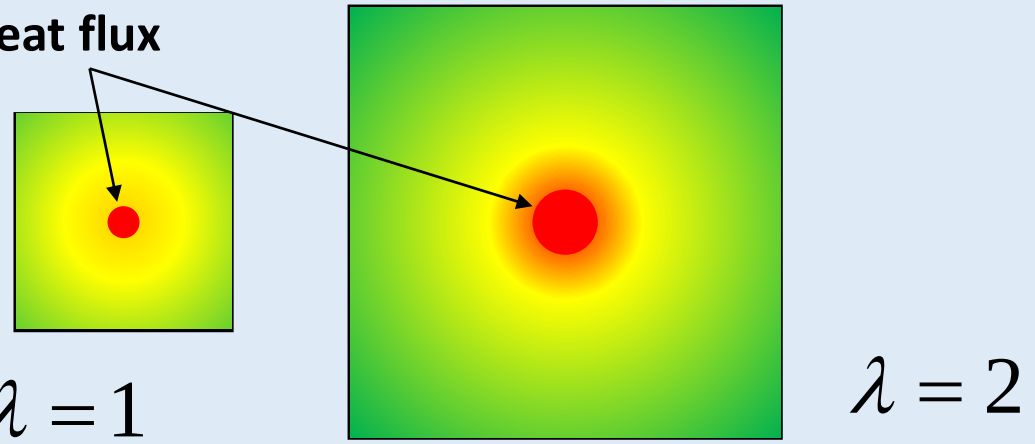
Linear scaling rule:

$$\lambda = \left(\frac{V}{V_0} \right)^{\frac{1}{3}}$$

$$h = \lambda \cdot h_0 \quad l = \lambda \cdot l_0$$

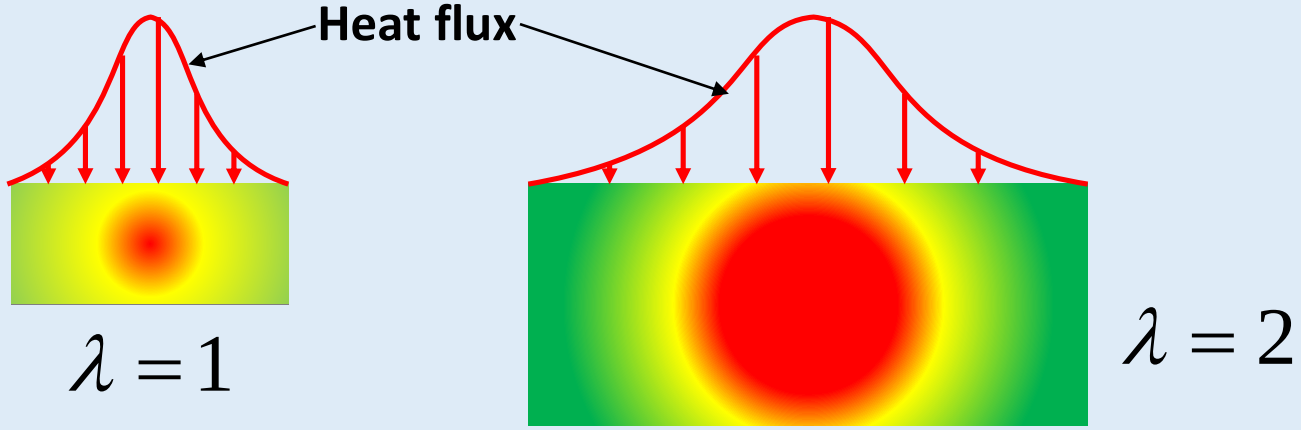
$$p = p_0 \quad T = T_0$$

Fluid domain temperature



Not scalable

Solid domain heat transfer



Not scalable

Scaling

Are lubricating interfaces linearly scalable?

- *No*
- Only because that hydrostatic/hydrodynamic pressure distribution, and fluid/solid domain temperature distribution are not scalable.

Shang, L., Ivantysynova, M. (2018)

Is there an effective scaling rule?

- *Yes*
- Scaling guide has been proposed based on the findings from the scaling study.
- More effective scaling rules are proposed for three lubricating interfaces.

Shang, L., Ivantysynova, M. (2016,2017,2018)

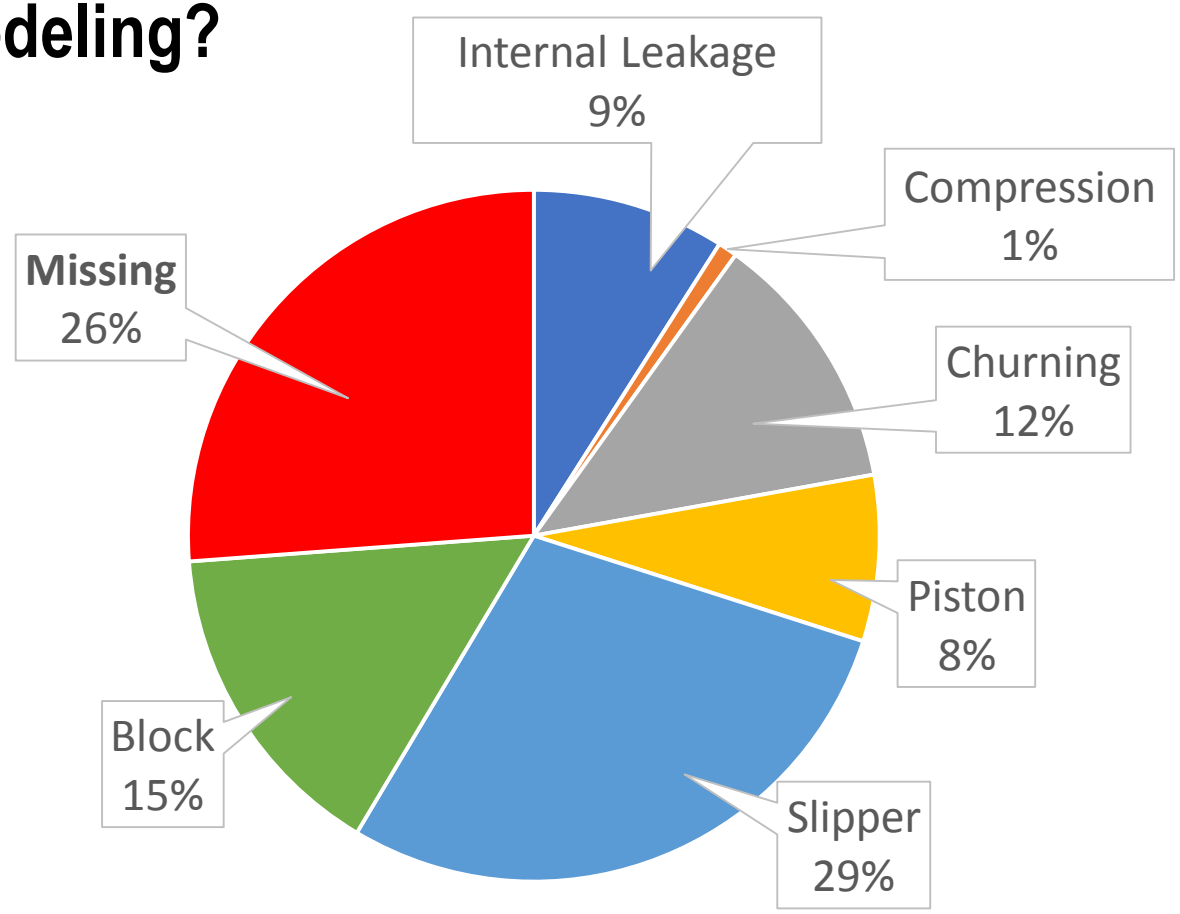
Outlook

Where are we on axial piston machines modeling?

Power loss distribution:

Simulation vs measurement

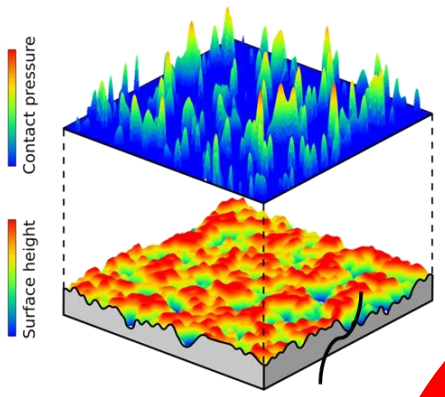
52cc unit, 50°C, 50%, 2000 rpm, 170 bar

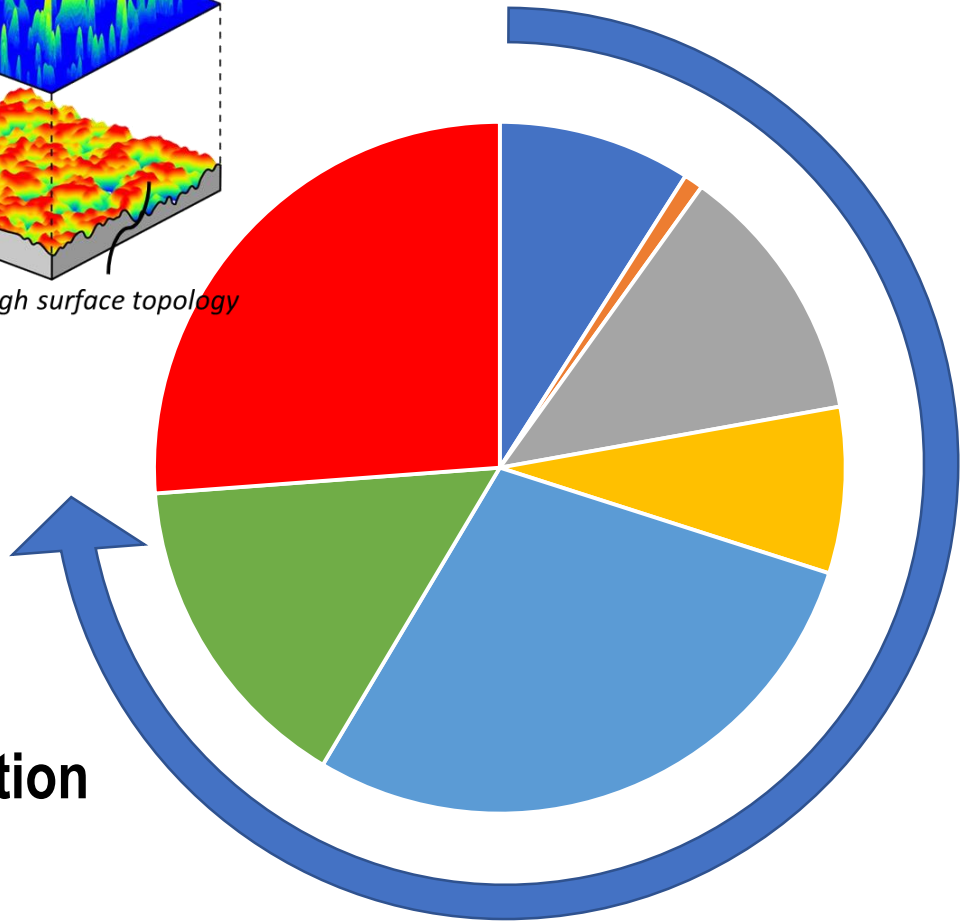


Hasko, D., Shang, L., et al. (2019)

Outlook

- **Micro-scale tribological characterization**
  - **Measurement-driven simulation**
  - **Novel test rig for small contact patch measurement**

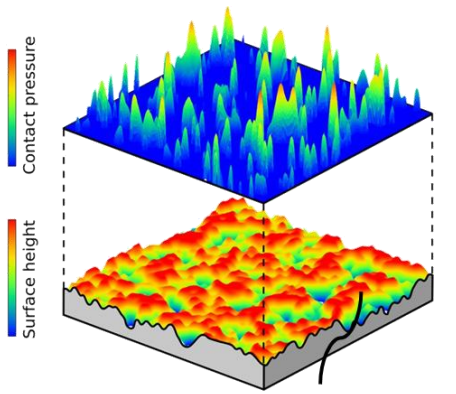




75% accurate on power loss prediction

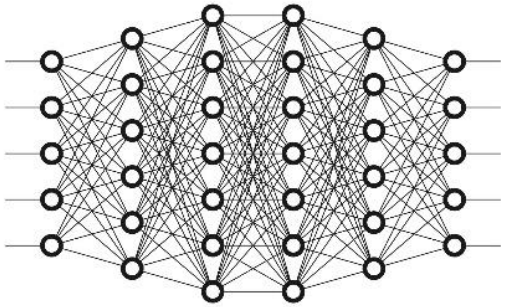
Outlook

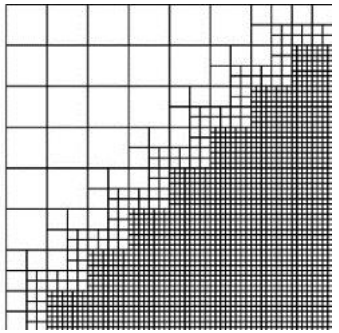
- **Micro-scale tribological characterization**
  - **Measurement-driven simulation**
  - **Novel test rig for small contact patch measurement**



Rough surface topology

- **Computational efficiency optimization**
  - **Contribution-based computational power allocation**
  - **AI-aided simulation**





Conclusion

- Lubricating interfaces in axial piston machines are difficult to design
- Modeling tool helps to understand the essential insight of lubricating interface behavior
- Innovative design and innovative design process are made possible by the modeling tool
- Lubricating interface are not linear scalable due to thermal and hydrostatic/dynamic effects only
- Outlook of the model development is discussed

Thank you!