Efficiency by design:
Piston pumps and motors with predefined tribological systems

Jürgen Berbuer

Efficiency by design

1. Basic ideas about energy dissipation in hydrostatic machines
2. First step: Eliminate locations of dissipation (as far as possible)
3. Second step: Replace mixed friction by Newtonian friction
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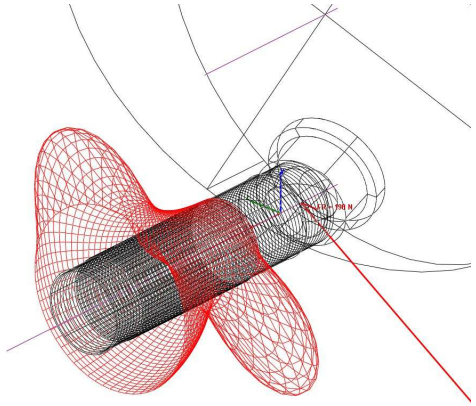
5. Concept of a novel axial tilt piston machine
6. Conclusion

Energy dissipation in hydrostatic machines

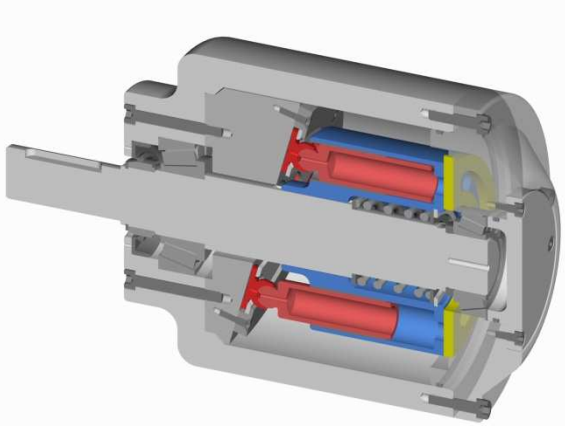
In established hydrostatic machines, e.g. axial piston swashplate machines we find energy dissipation in form of

- leakage losses through gaps
- friction losses in sliding pairings



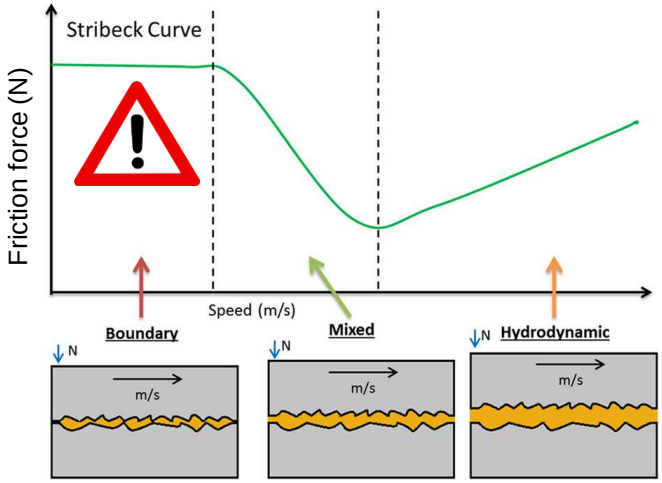
Calculation of losses is difficult, because gap dimensions are changing with load, speed and viscositiy

Simulations of mixed friction trobological systems are possible, but sophisticated and expensive



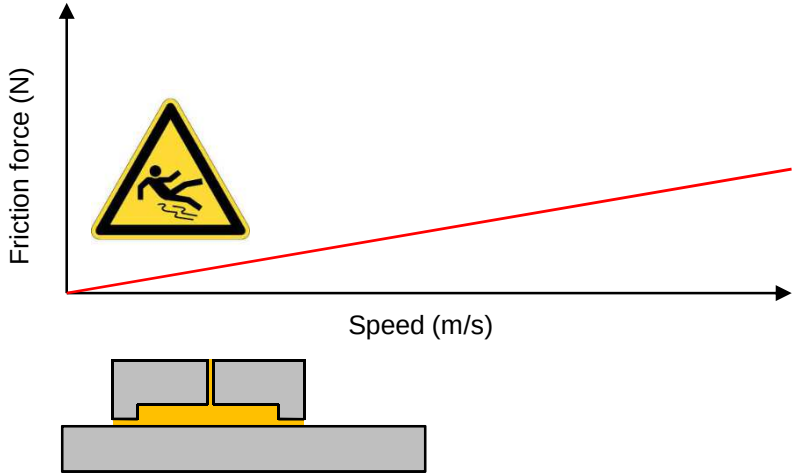
Mixed friction vs. hydrostatic bearing

Established tribosystems with mixed friction and hydrostatic load reduction

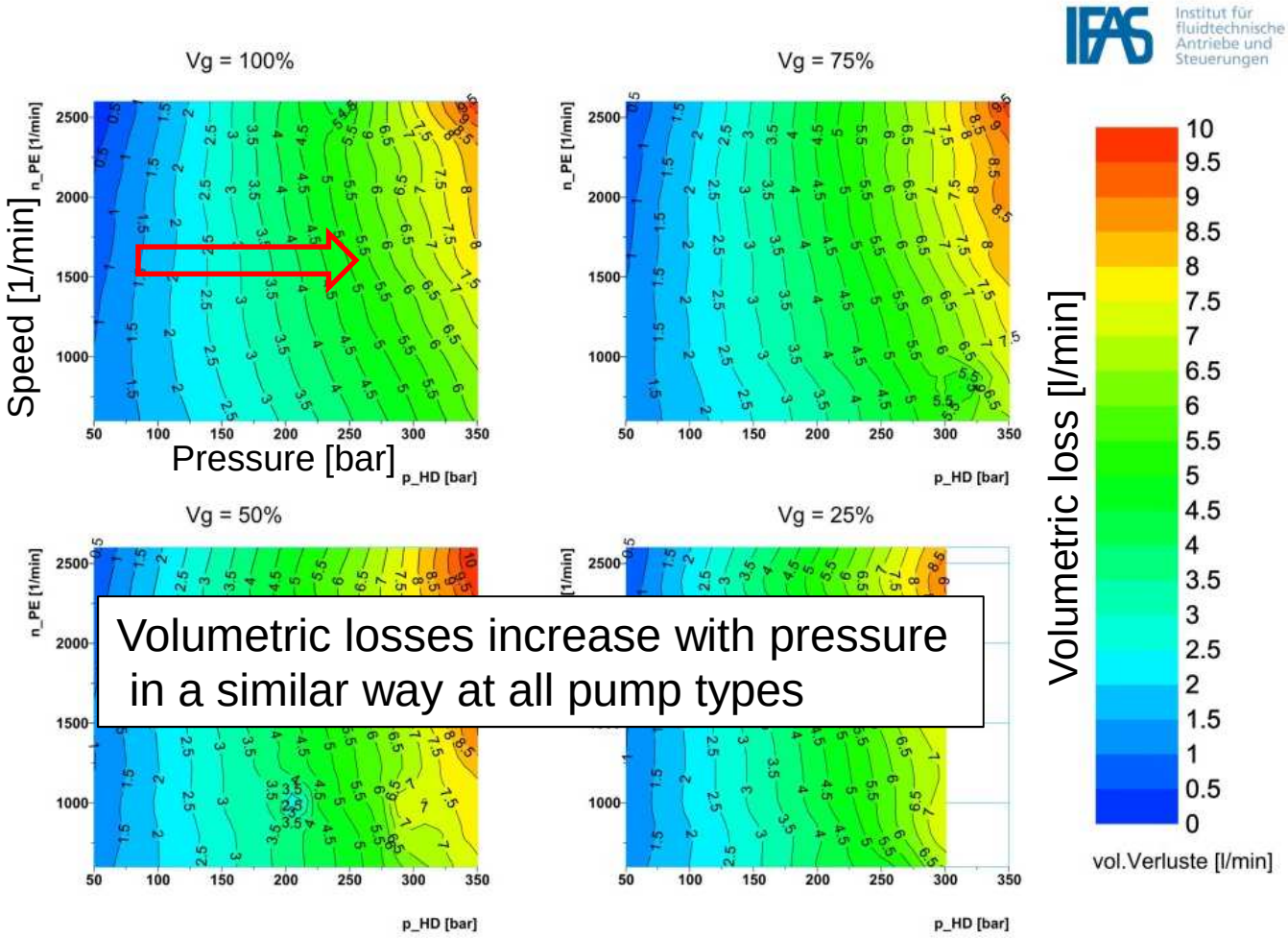


< 6µm

We propose the transition to full-featured hydrostatic bearings



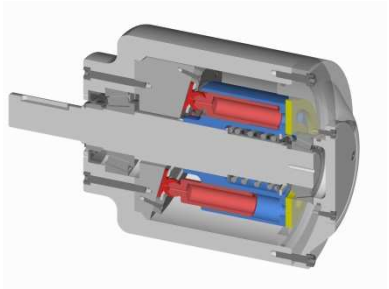
Volumetric losses (measured)



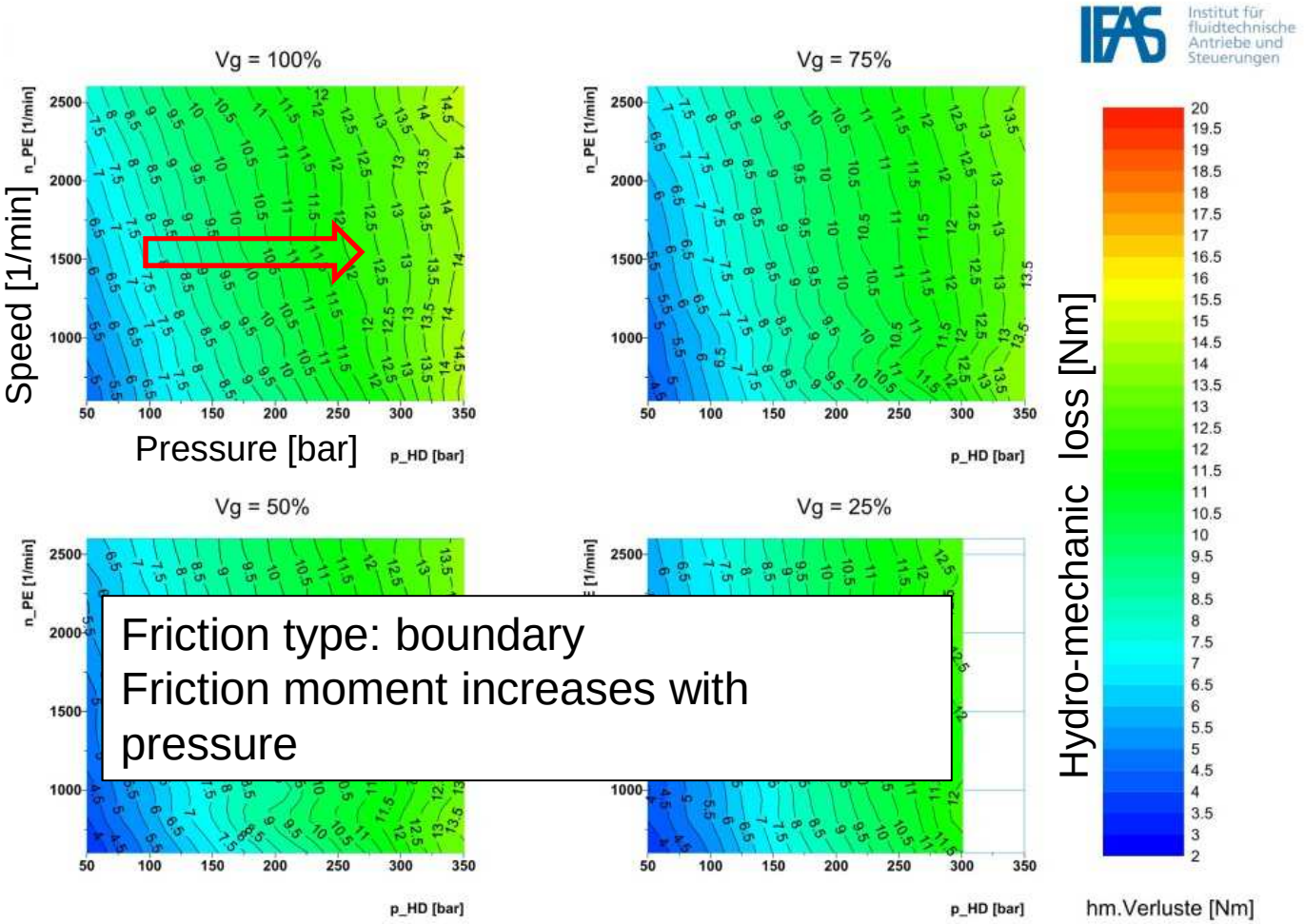
Institut für fluidtechnische Antriebe und Steuerungen

Volumetric losses displacement
100%
75%
50%
25%

Pump type:
Swashplate Nr. 1
$V = 45\ cm^3$



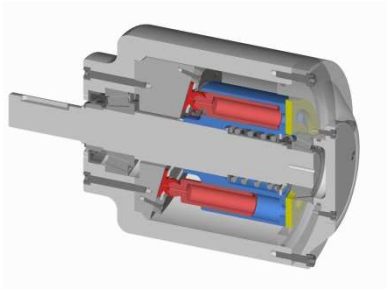
Hydro-mechanic losses (measured)



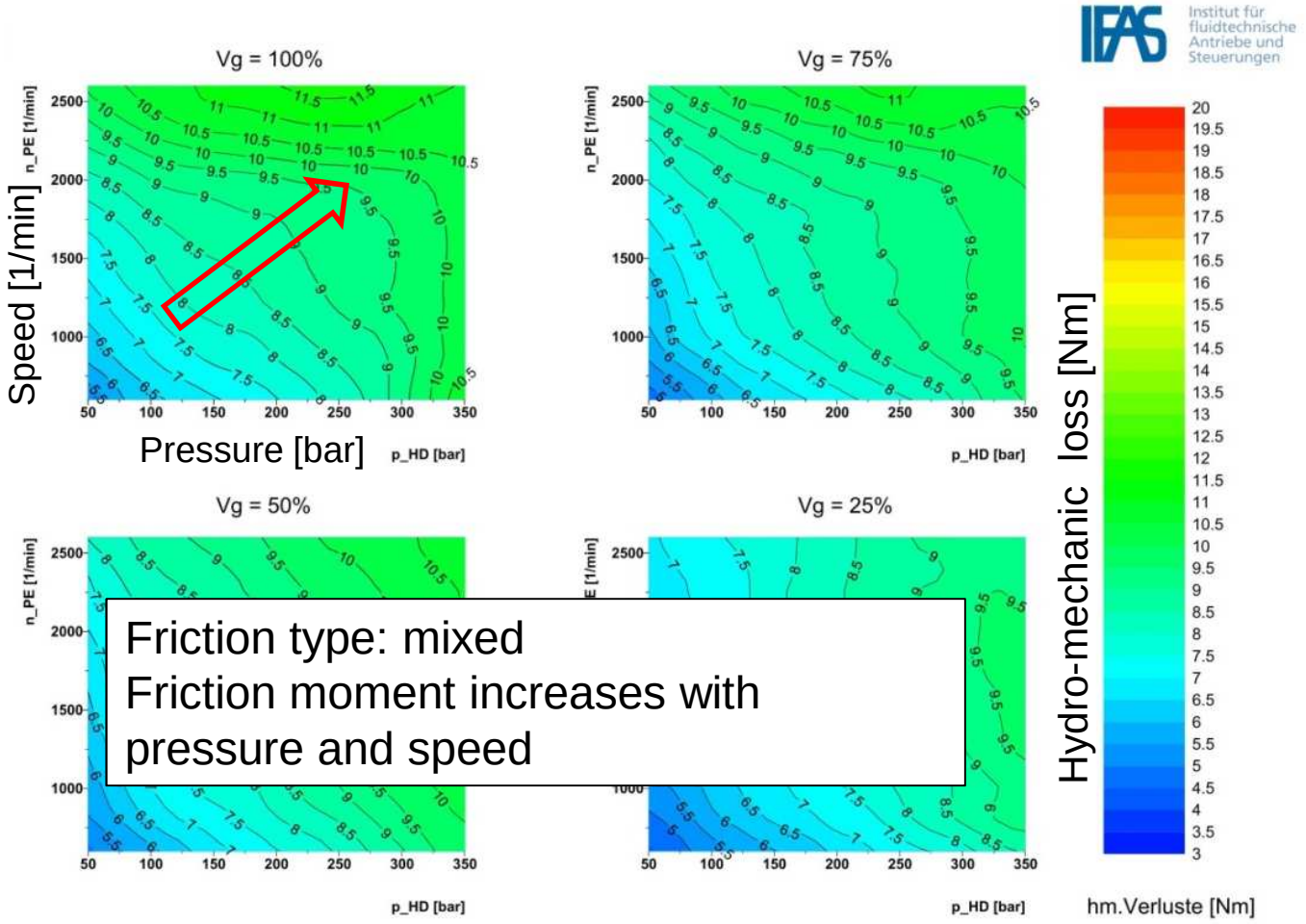
Friction type: boundary
Friction moment increases with pressure

Hydro-mechanic losses [Nm]
displacement
100%
75%
50%
25%

Pump type:
Swashplate Nr. 1
V = 45 cm^3



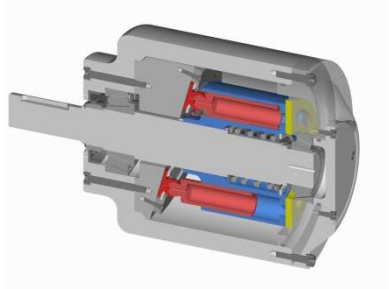
Hydro-mechanic losses (measured)



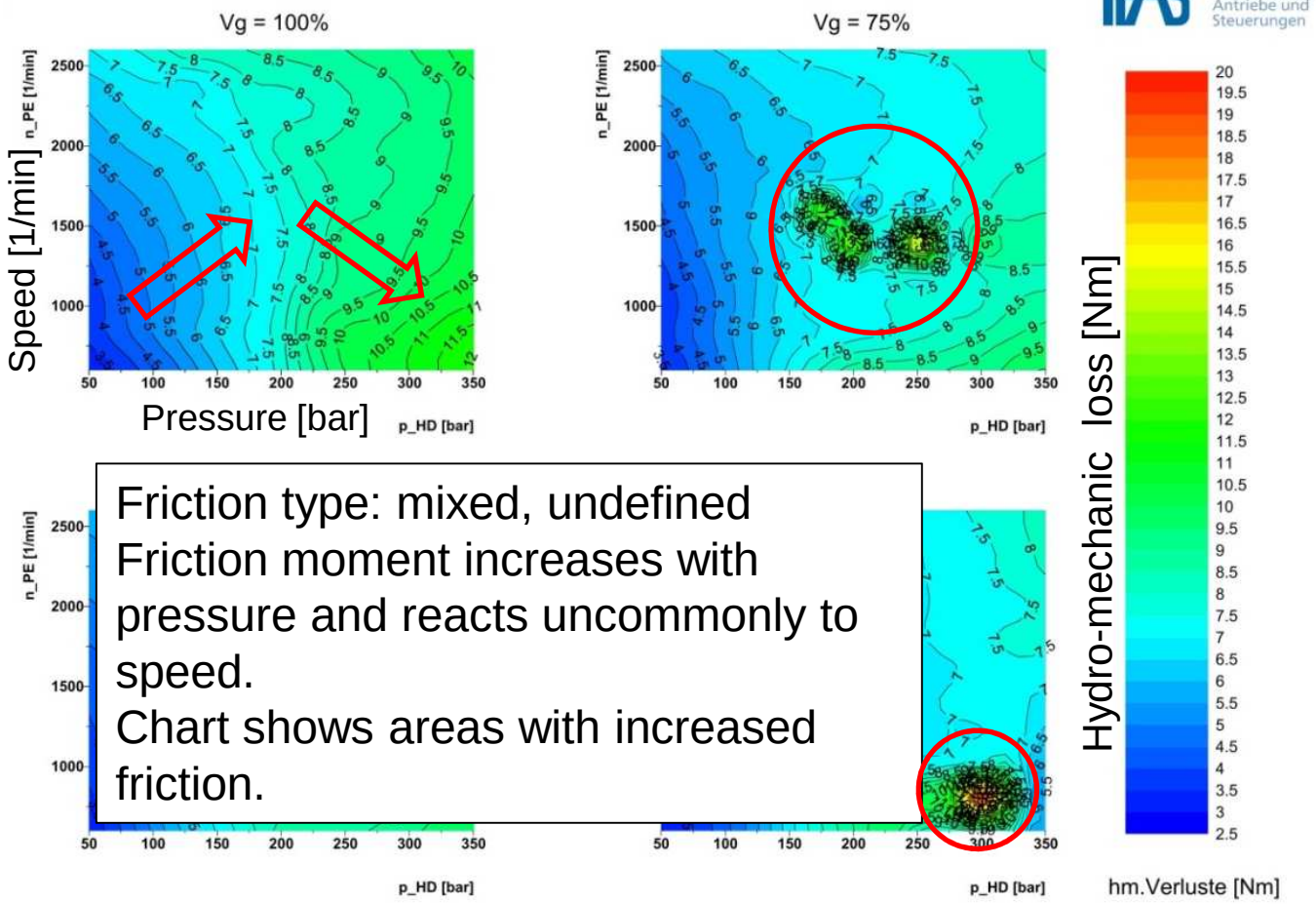
Friction type: mixed
Friction moment increases with pressure and speed

Hydro-mechanic losses [Nm]
displacement
100%
75%
50%
25%

Pump type:
Swashplate Nr. 2
V = 45 cm^3



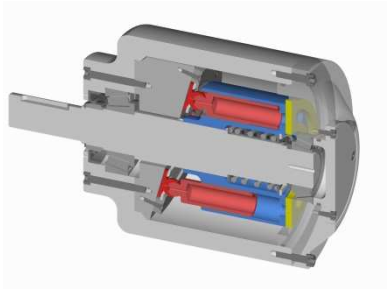
Hydro-mechanic losses (measured)



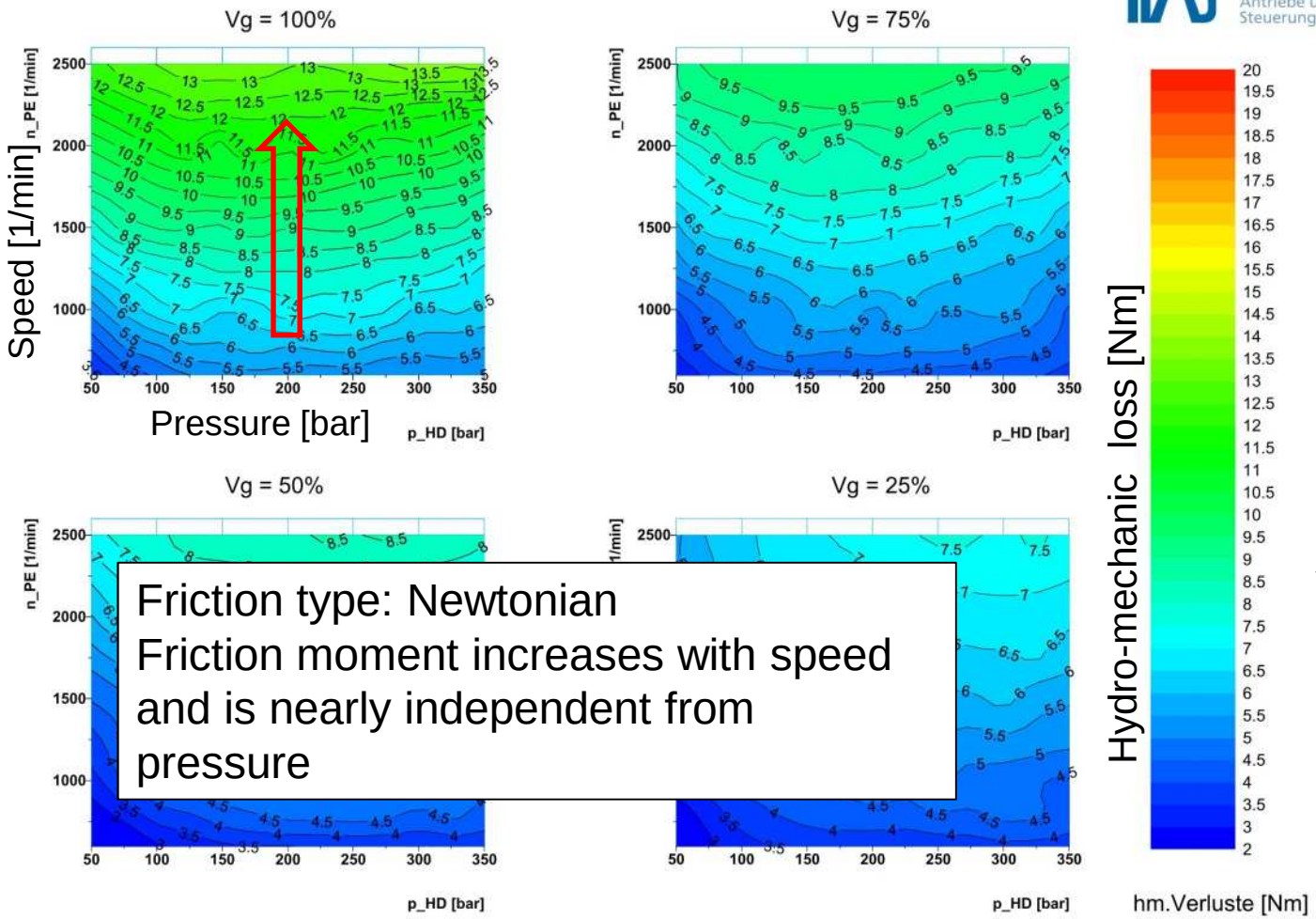
Friction type: mixed, undefined
Friction moment increases with pressure and reacts uncommonly to speed.
Chart shows areas with increased friction.

Hydro-mechanic losses [Nm]
displacement
100%
75%
50%
25%

Pump type:
Swashplate Nr. 3
V = 45 cm^3



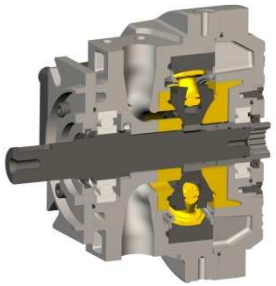
Hydro-mechanic losses (measured)



Friction type: Newtonian
Friction moment increases with speed and is nearly independent from pressure

Hydro-mechanic losses [Nm]
displacement
100%
75%
50%
25%

Pump type:
RAC
V = 40 cm³



Lessons learned

In established HM the optimization of the dominating tribocontacts is a topic of empirical expert knowledge with a high demand of time and testing.

This means long development periods and incertitude in variant design.

In opposite, we are working on a method to design and optimize a hydrostatic machine in a direct and target-oriented way.

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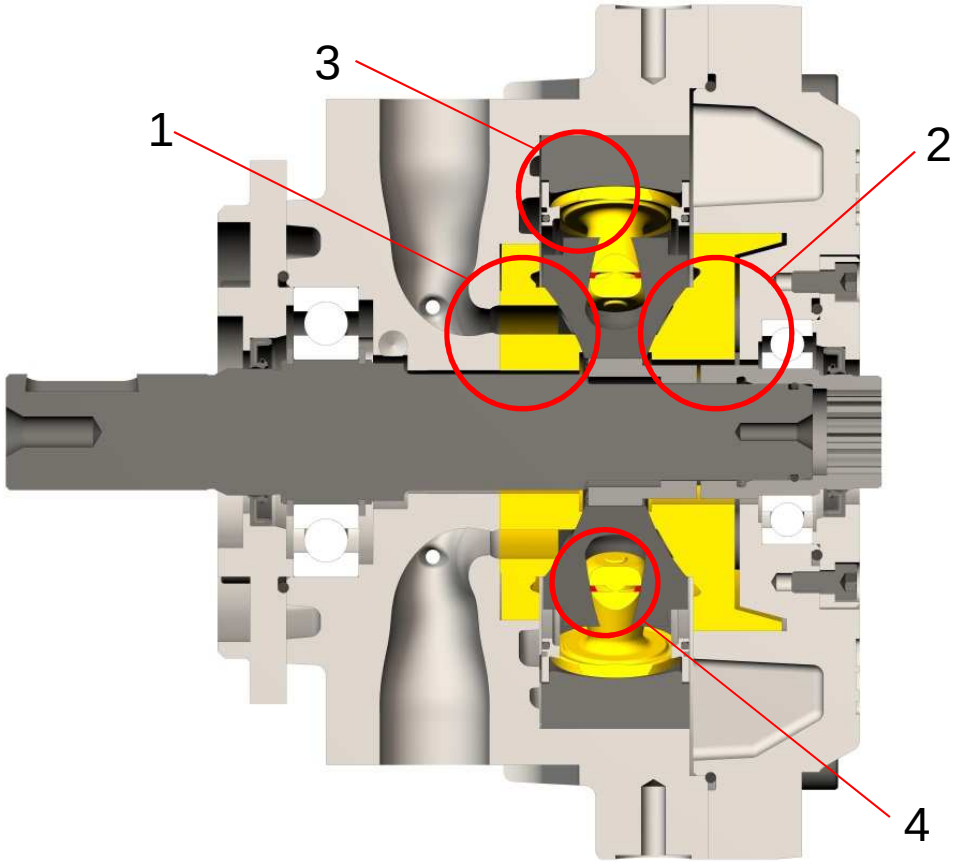
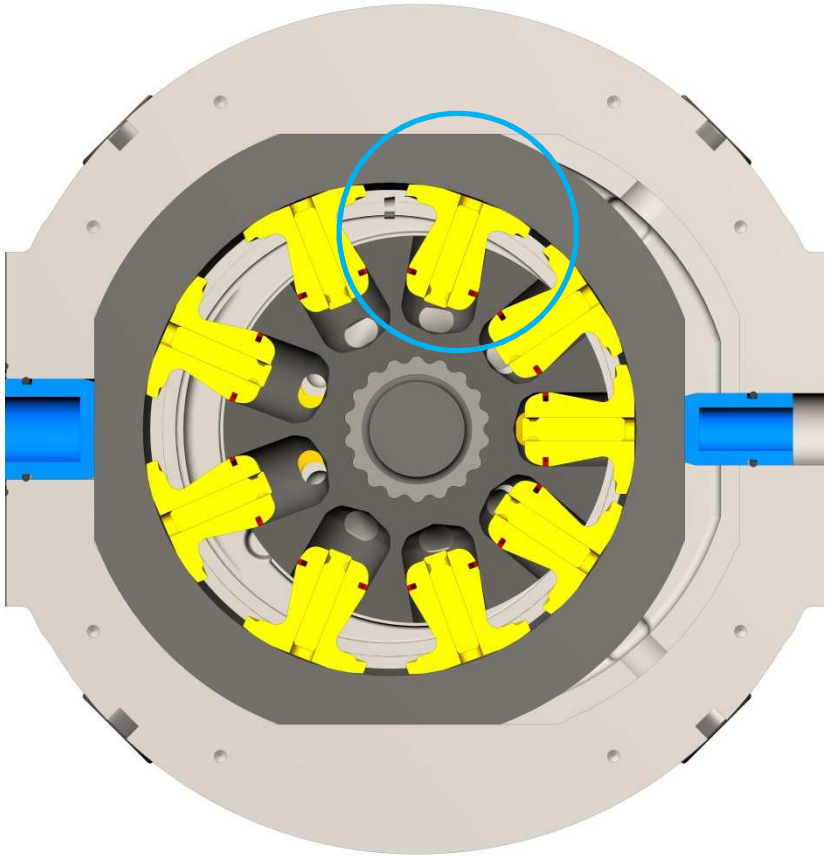
Locations of dissipation (RAC)





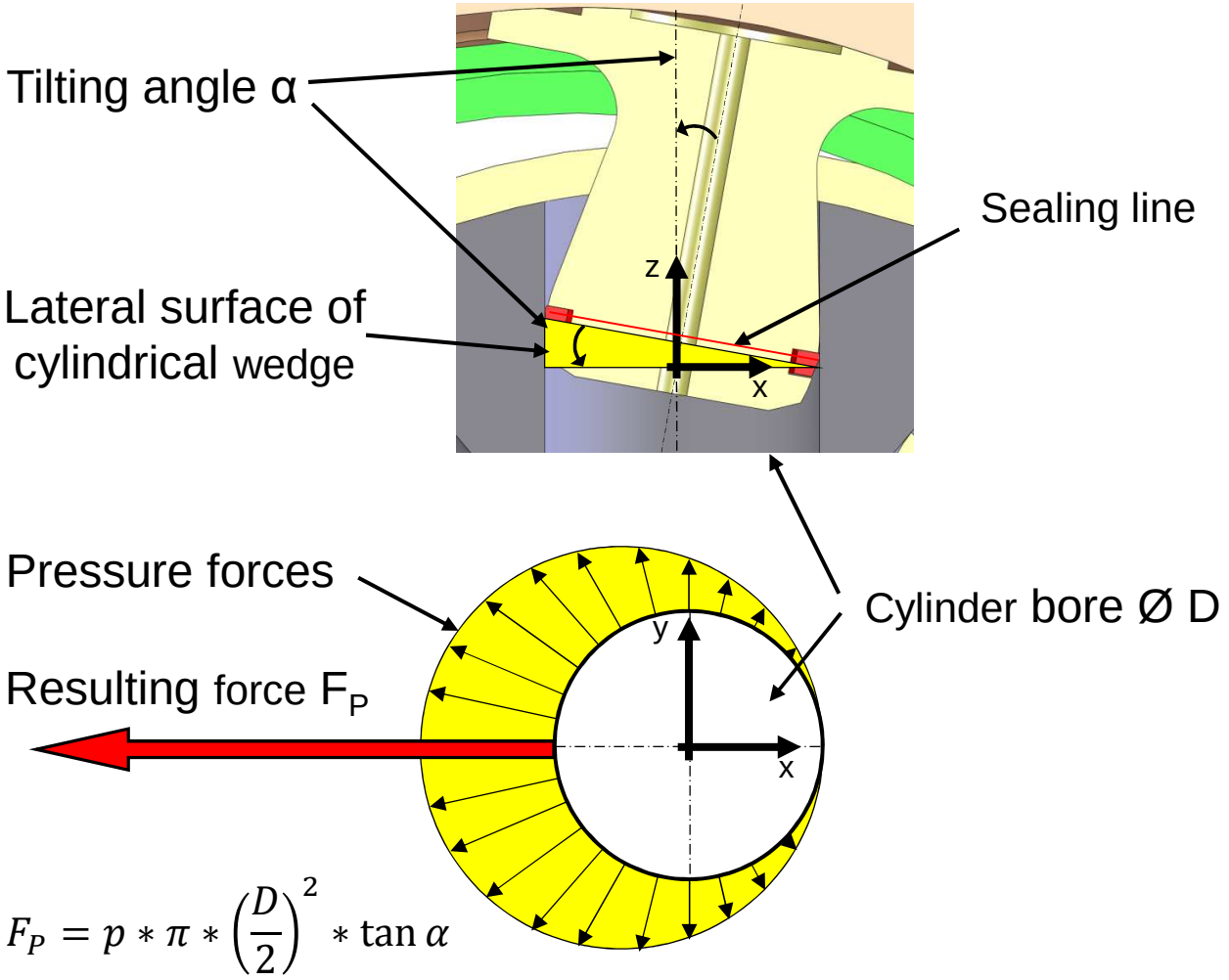
1 Port plate
2 Conterbalance plate
3 Piston slipper
4 Piston ring

Distinction:
Tilt piston design

Tilt piston design

Result:

Direct transmission from pressure to torque on the cylinder wall



$$F_P = p * \pi * \left(\frac{D}{2}\right)^2 * \tan\alpha$$

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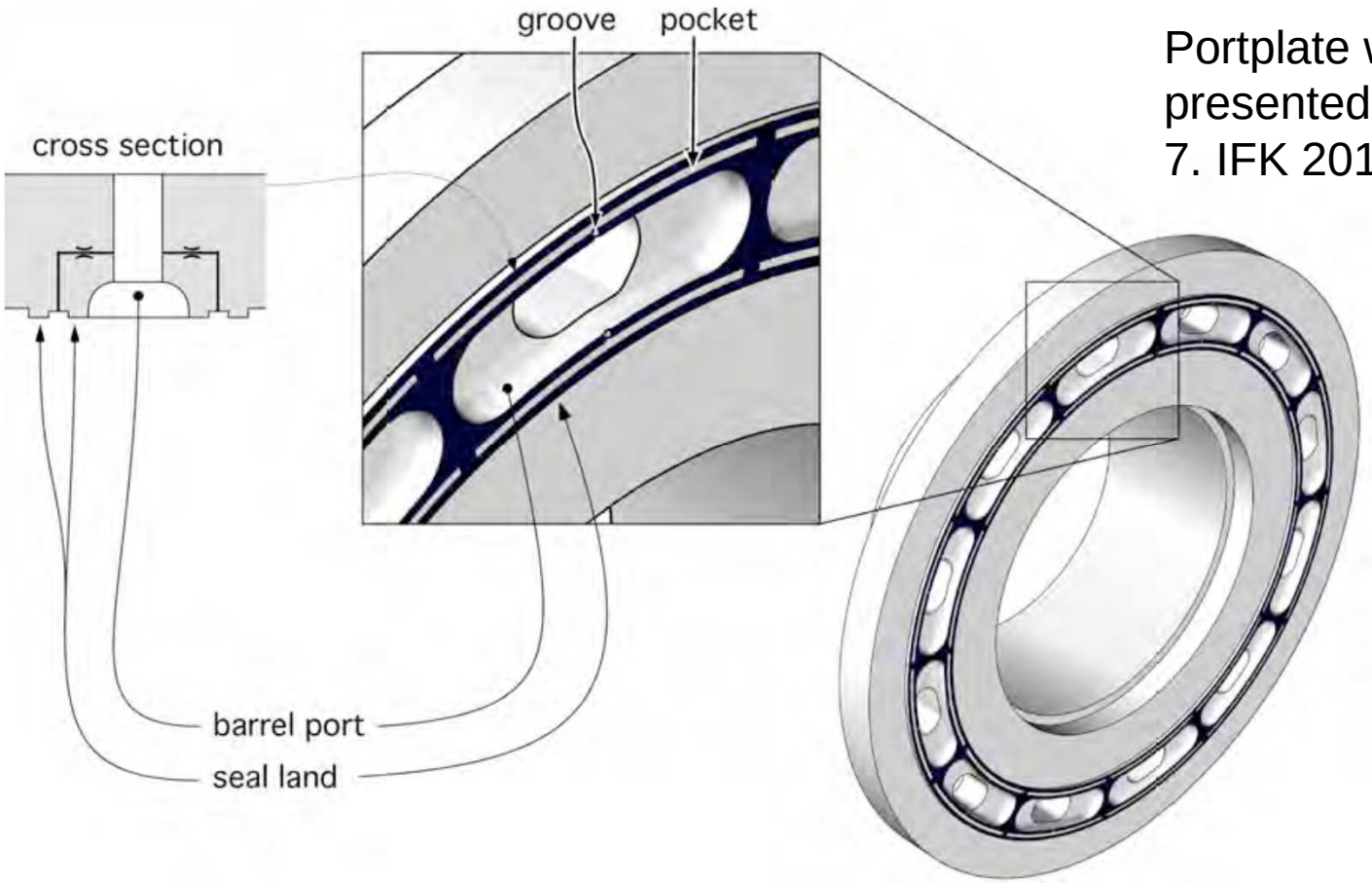
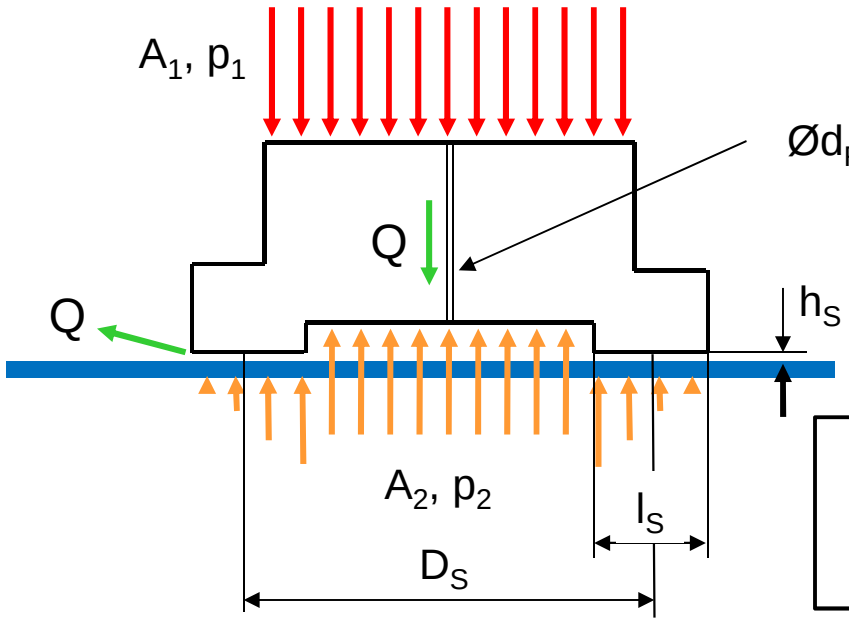
Hydrostatic bearings in hydrostatic machines

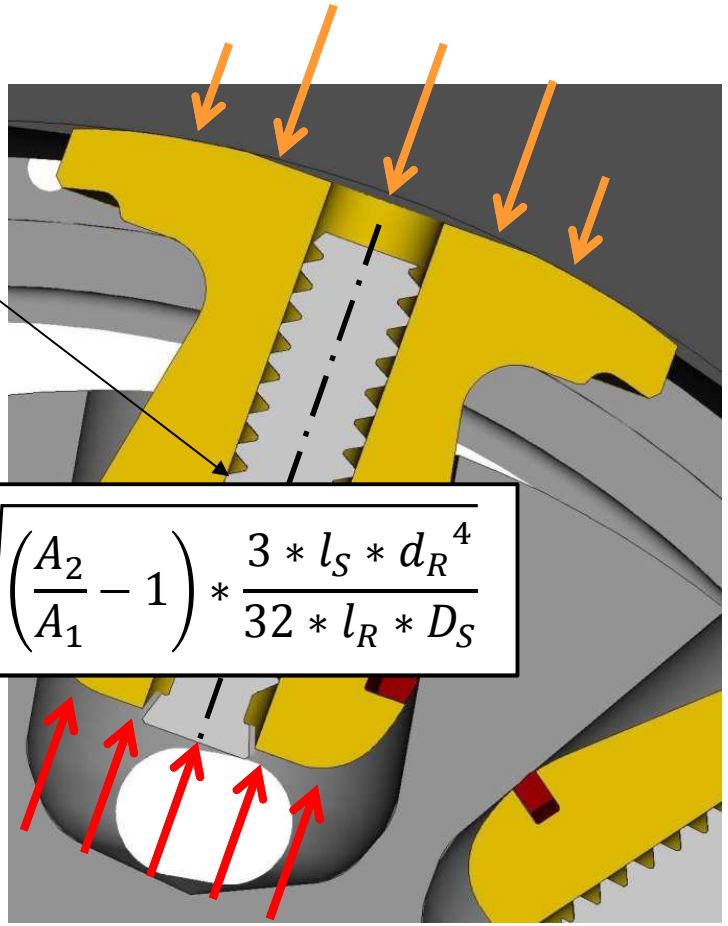


Portplate with pockets
presented by P. Achten
7. IFK 2010

Hydrostatic bearings in tilt piston slippers



$$h_S = \sqrt[3]{\left(\frac{A_2}{A_1} - 1\right) * \frac{3 * l_S * {d_R}^4}{32 * l_R * D_S}}$$



increased slipper area $A_2 > A_1$

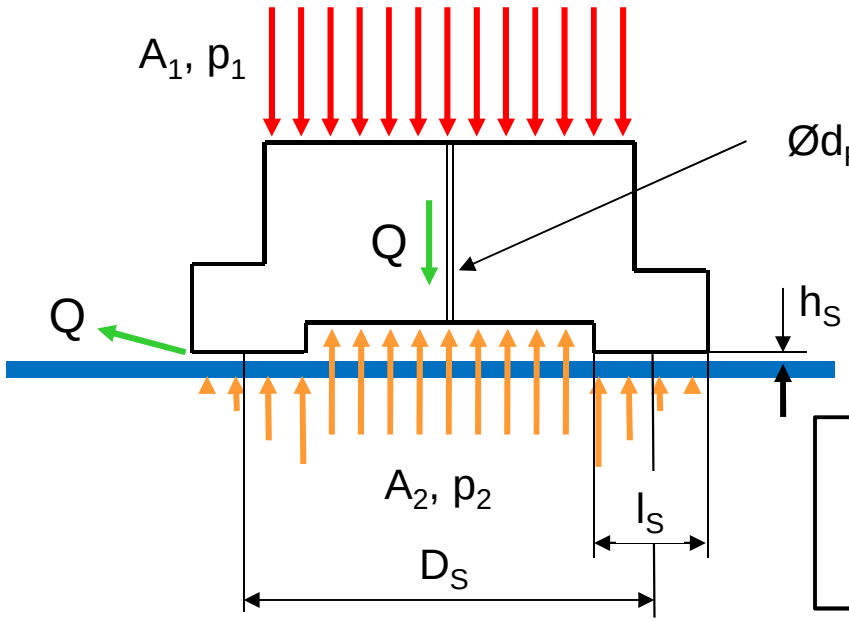
reduced slipper pressure $p_2 < p_1$

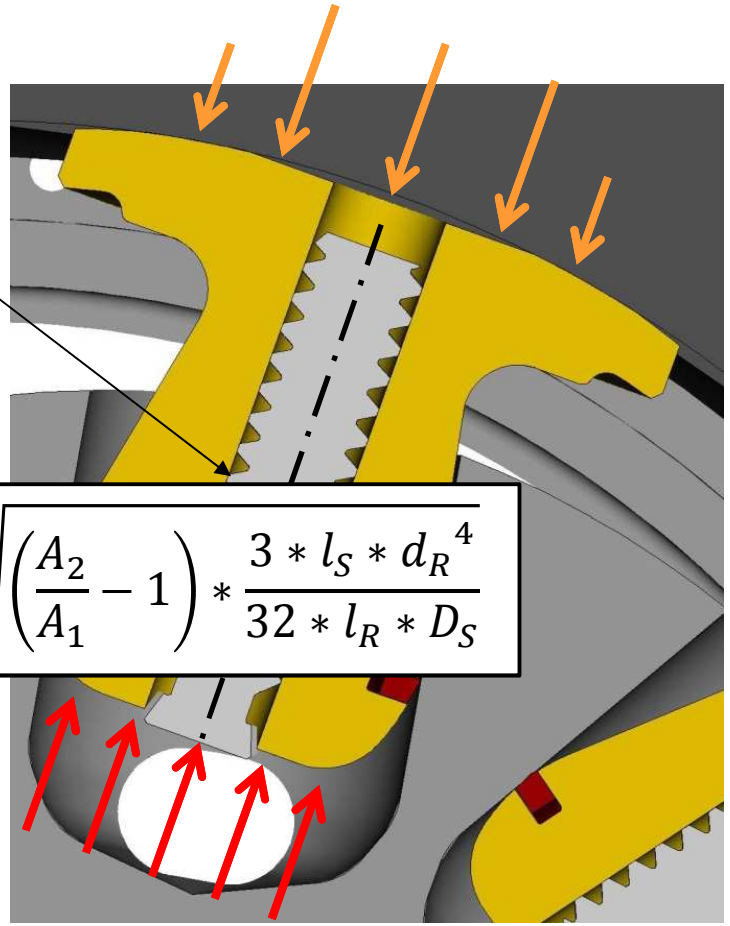
result:

self-controlled gap height h_s

depending on geometric factors only (not on viscosity, pressure or speed)

Hydrostatic bearings in tilt piston slippers





$$h_S = \sqrt[3]{\left(\frac{A_2}{A_1} - 1\right) * \frac{3 * l_S * {d_R}^4}{32 * l_R * D_S}}$$

Result:
The use of full-featured hydrostatic bearings enables the designer to choose and optimize the gaps of a hydrostatic machine

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Loss and efficiency calculation

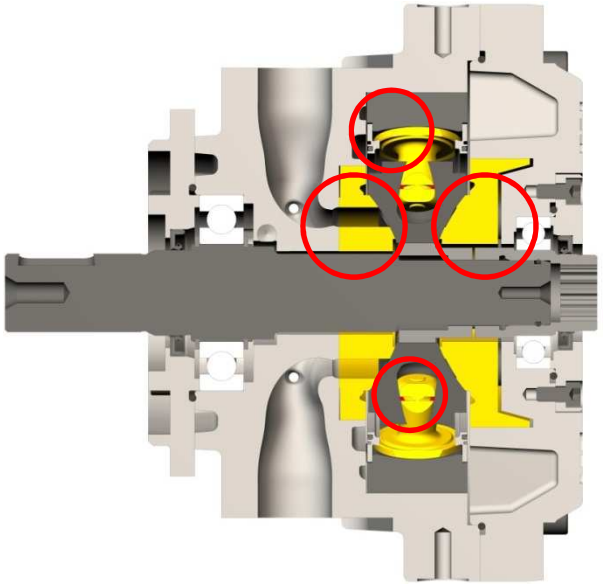
For moved tribocontacts with defined gap height h the volumetric and hydromechanic losses can be calculated and summed up for the whole machine:

$$Q_{loss} = \sum_i \frac{\Delta p_i \cdot b_i \cdot (h_i)^3}{12 \cdot \eta \cdot l_i}$$ (Leakage flow)

$$P_{Qloss} = p \cdot Q = p \cdot \sum_i \frac{\Delta p_i \cdot b_i \cdot (h_i)^3}{12 \cdot \eta \cdot l_i}$$

$$M_{loss} = \sum_i \frac{2 \cdot \pi \cdot r^2 \cdot n \cdot \eta \cdot A}{h_i}$$ (Newtonian friction momentum)

$$P_{Mloss} = M \cdot 2 \cdot \pi \cdot n = \sum_i \frac{4 \cdot \pi^2 \cdot r^2 \cdot n^2 \cdot \eta \cdot A}{h_i}$$

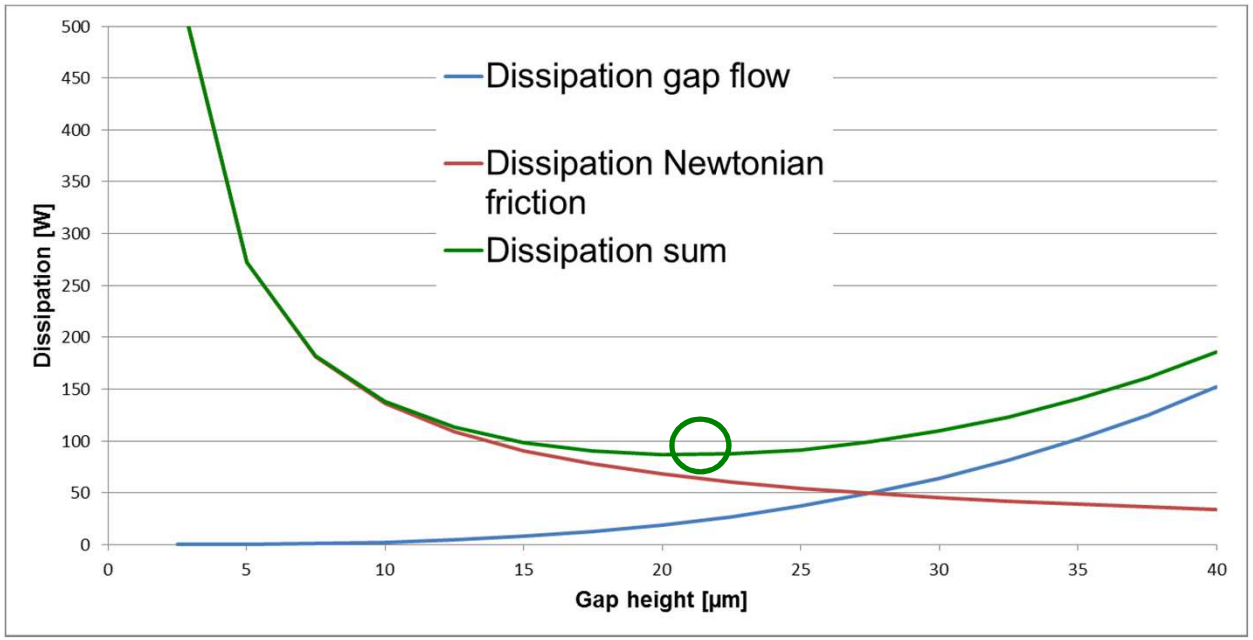


Δp	pressure difference
b	gap breadth
h	gap heigth
l	gap lenght
η	viscosity
r	radius (of movement)
n	rotational speed
A	contact area

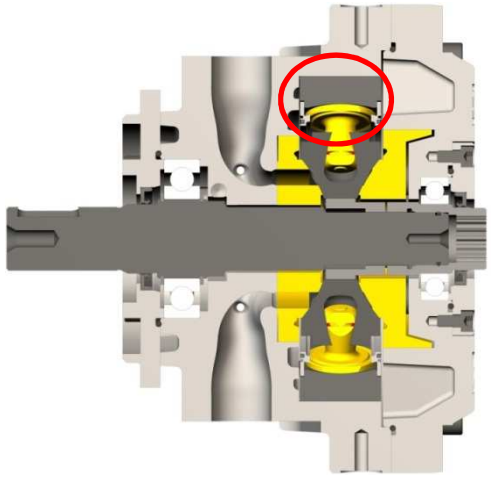
Loss and efficiency calculation

For a single tribological system you can find the optimum gap, depending on

- viscosity
- pressure
- speed



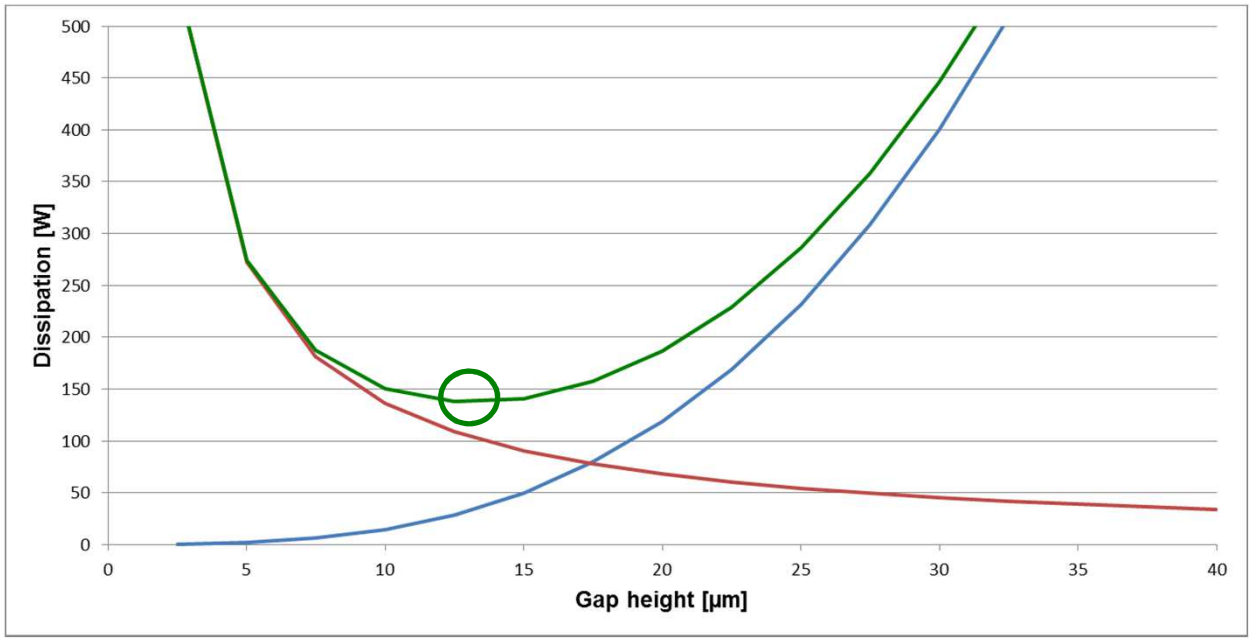
viscosity	25 mm²/s
pressure	100 bar
slipper speed	10 m/s



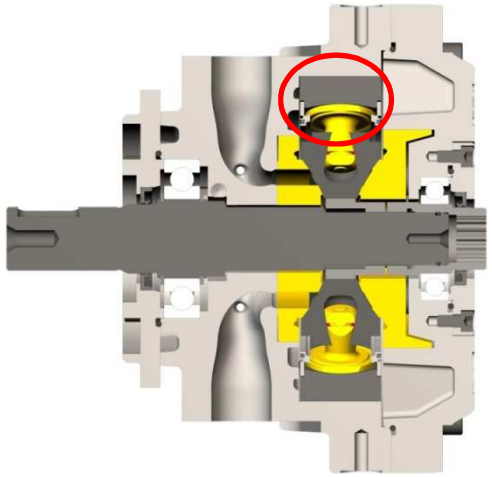
Loss and efficiency calculation

For a single tribological system you can find the optimum gap, depending on

- viscosity
- pressure
- speed



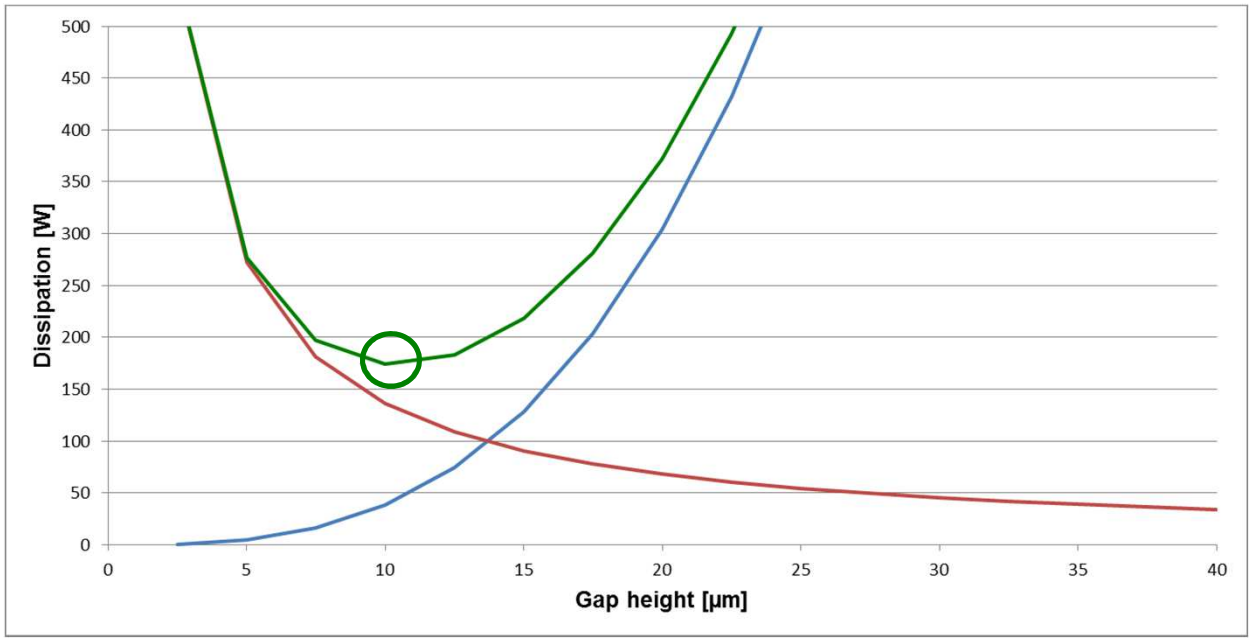
viscosity	25 mm²/s
pressure	**250 bar**
slipper speed	10 m/s



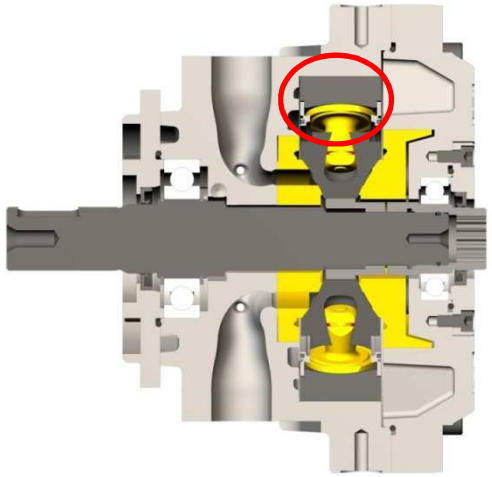
Loss and efficiency calculation

For a single tribological system you can find the optimum gap, depending on

- viscosity
- pressure
- speed



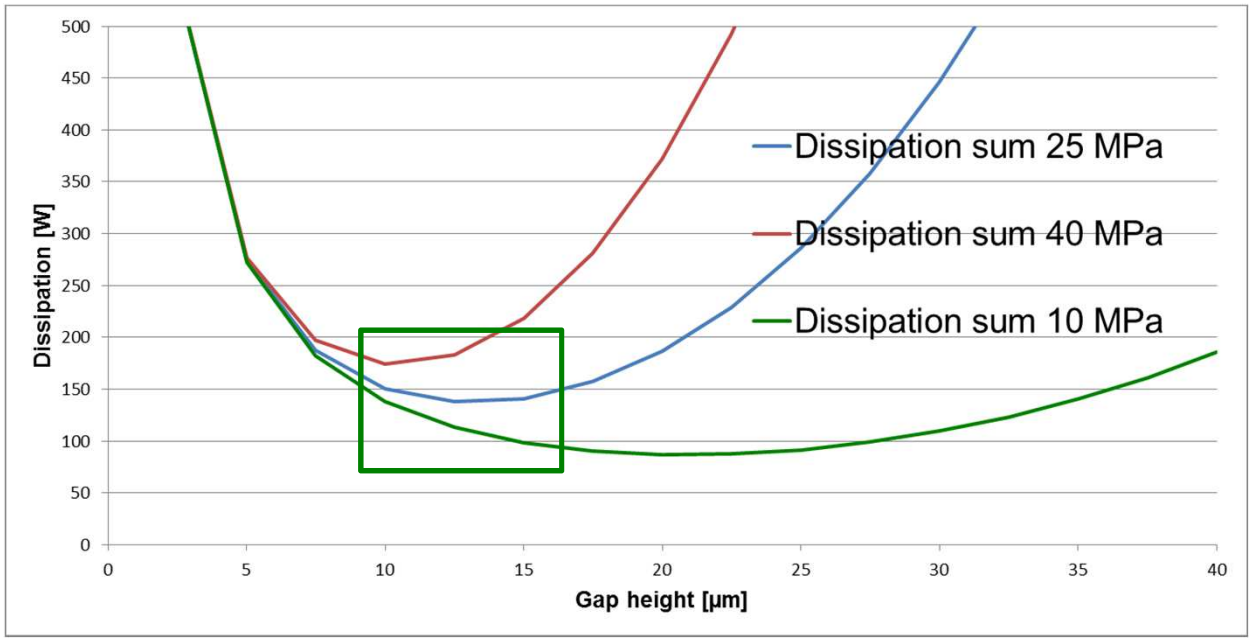
viscosity	25 mm²/s
pressure	**400 bar**
slipper speed	10 m/s



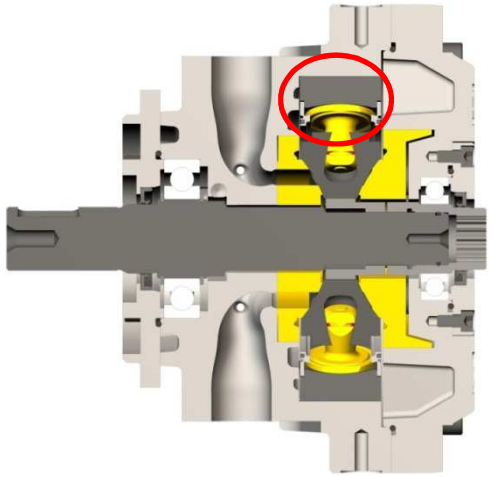
Loss and efficiency calculation

For piston slippers you find the optimum gap normally in the range between 9 µm to 20 µm

► a good compromise is possible



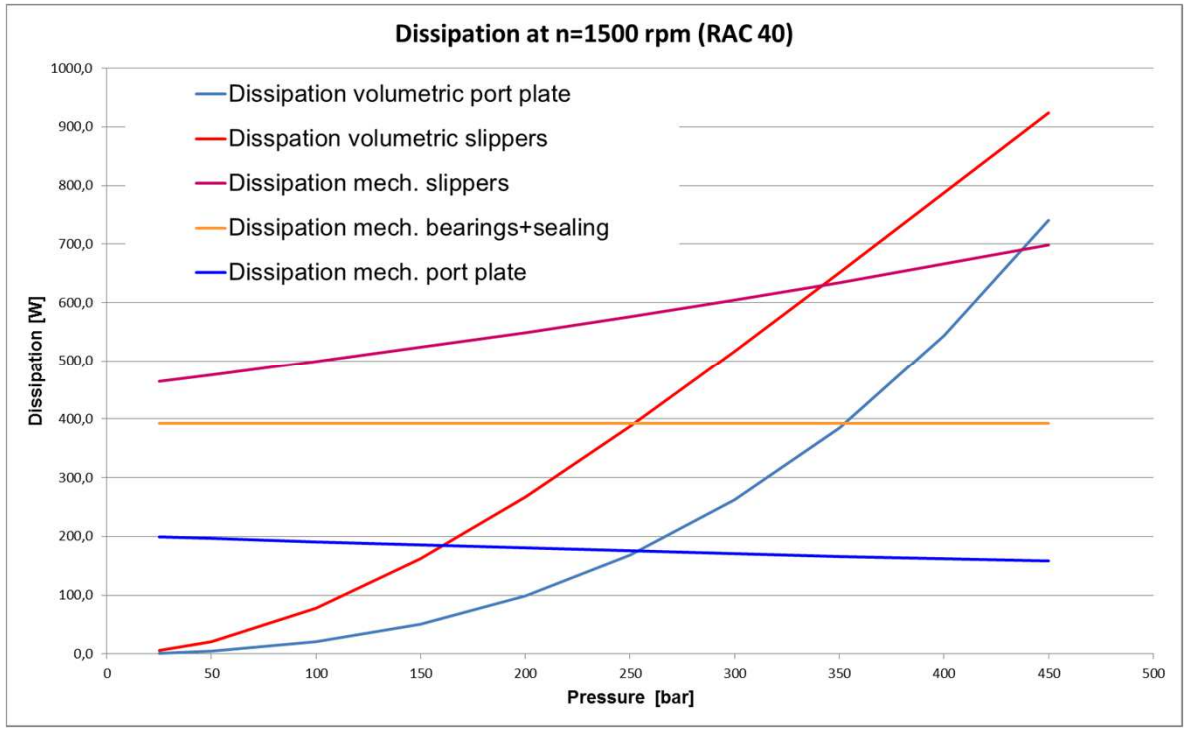
viscosity	25 mm²/s
pressure	100 / 250 / 400 bar
slipper speed	10 m/s



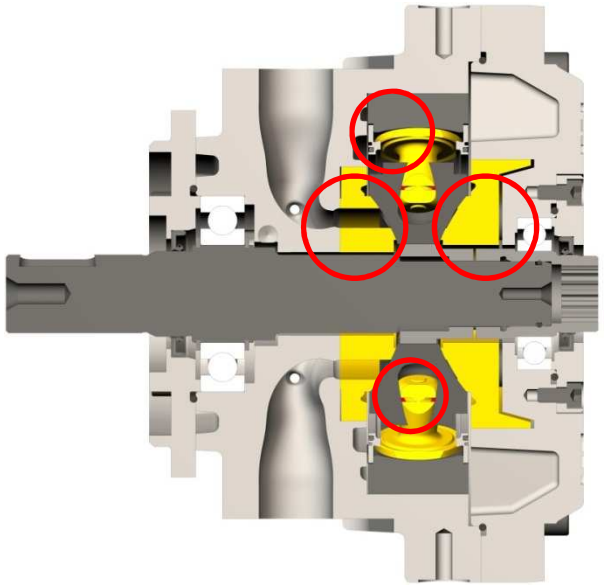
Loss and efficiency calculation

Chart of the specific losses in assignment to the locations and loss mechanisms

► targeted reduction of dissipation



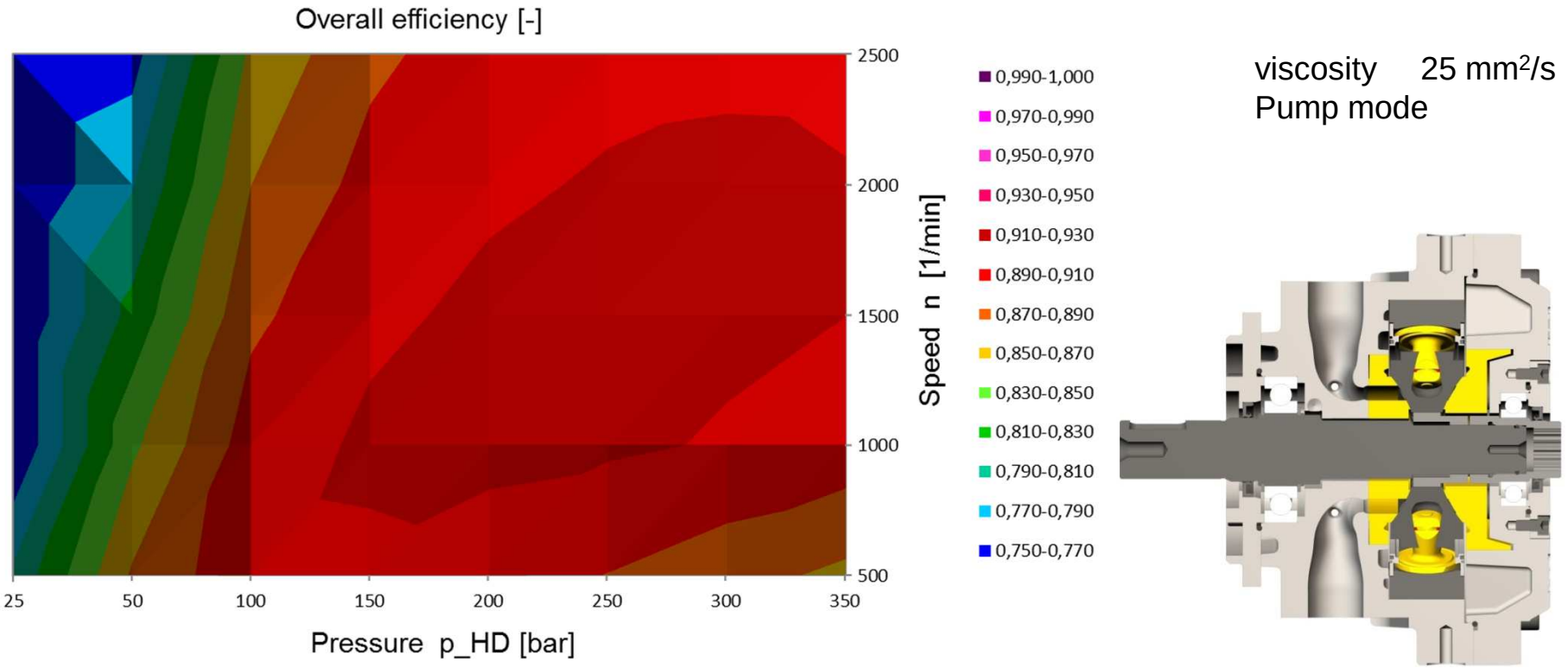
viscosity 25 mm^2/s



Loss and efficiency calculation

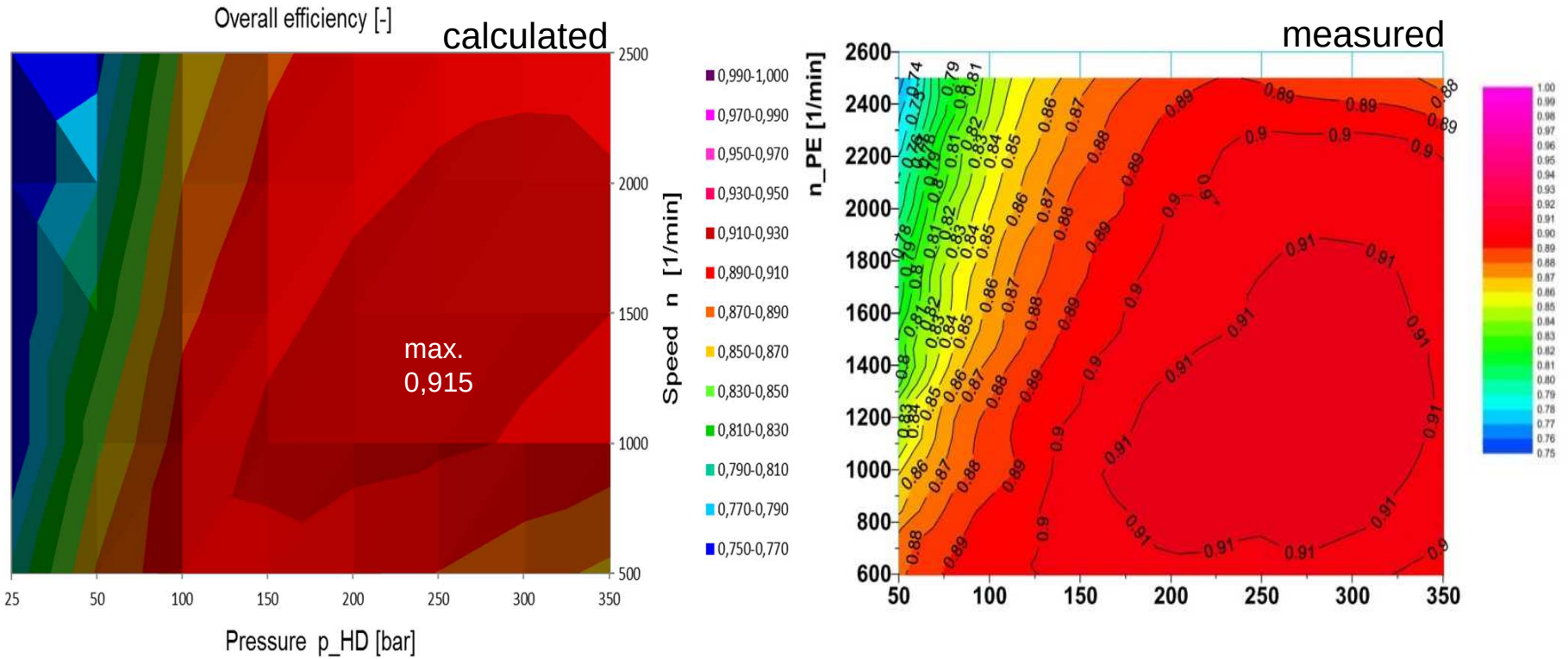
Overall efficiency chart calculated by loss analysis including the effects of

- viscosity change by pressure and
- elastic deformation of port plate



Loss and efficiency calculation in comparison

The comparison of the calculated overall efficiency with the IFAS measurements show rather similar charts.
Analysing the differences helps understanding the loss effects and improve the calculation.



Viscosity 25 mm²/s Pump mode

Loss and efficiency calculation

Overall efficiency chart calculated by loss analysis including the effects of

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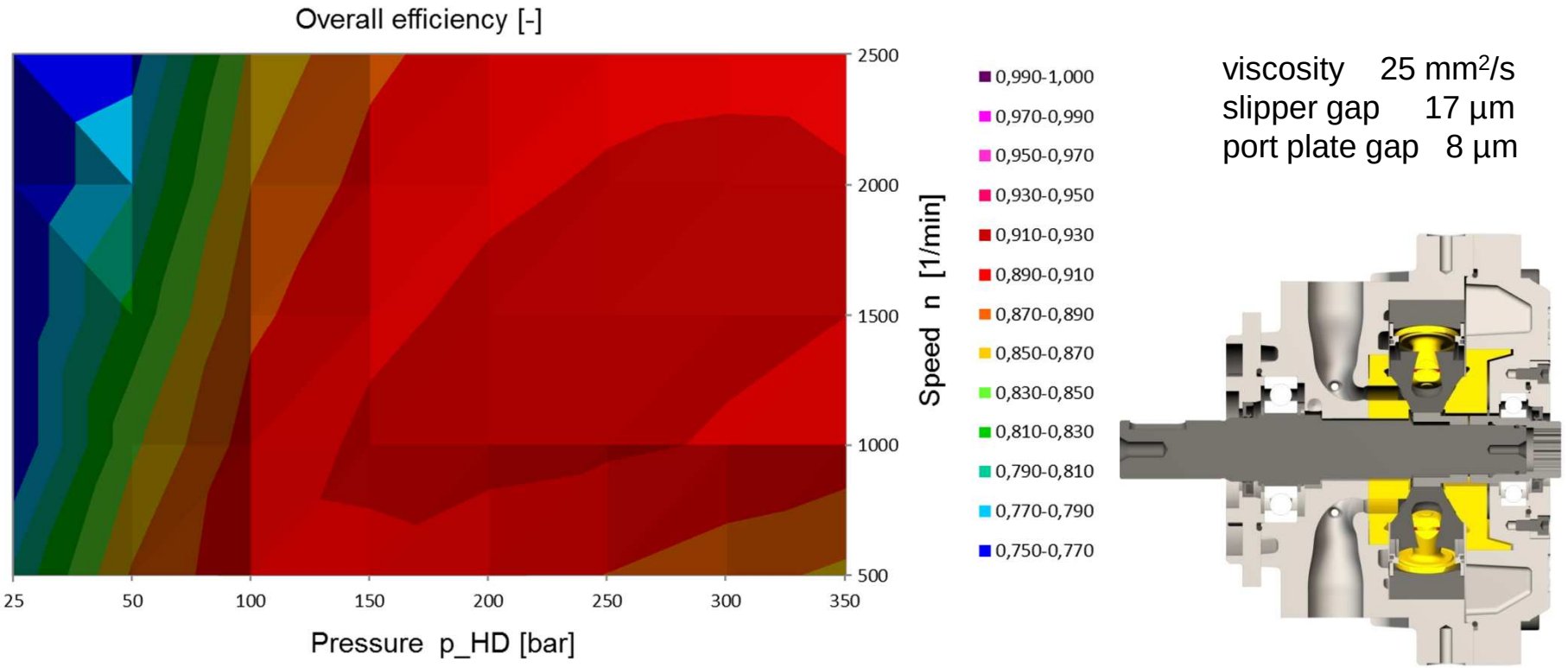
- elastic deformation of port plate

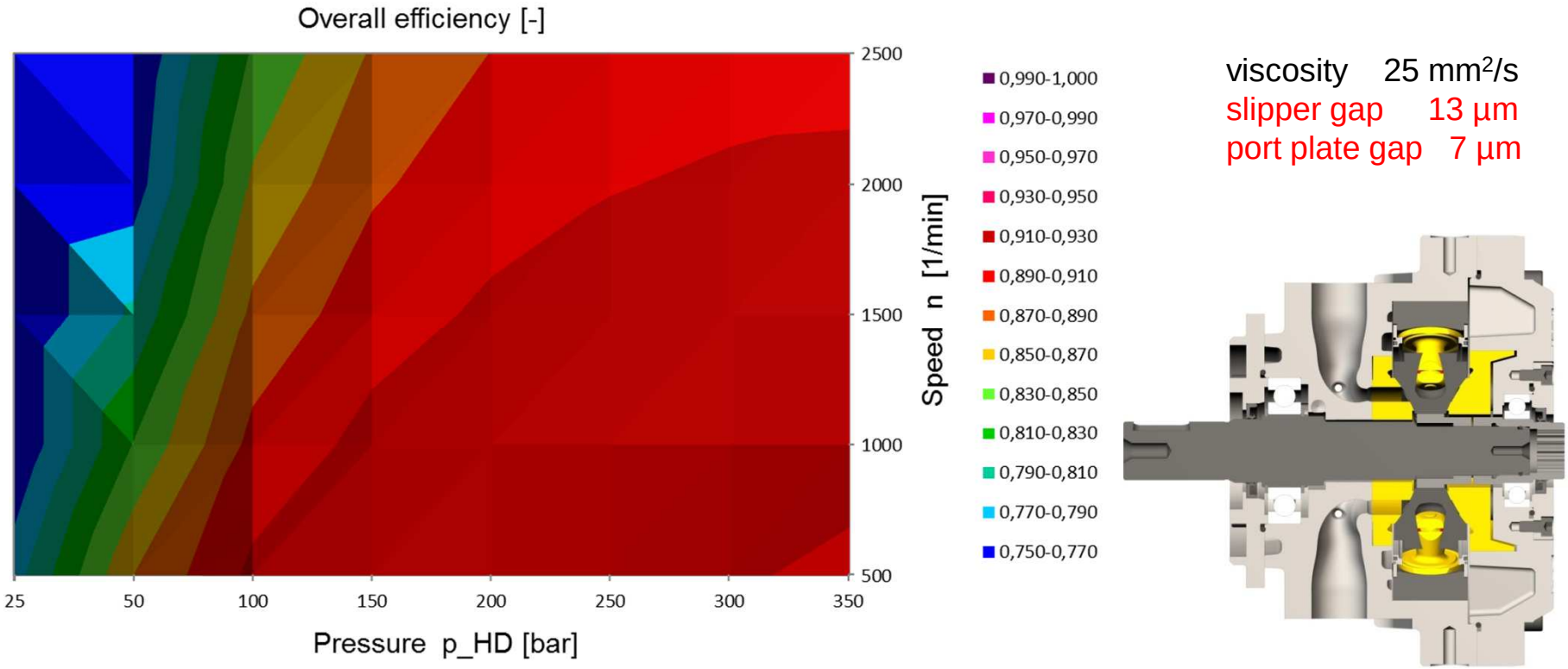


viscosity 25 mm²/s
slipper gap 17 µm
port plate gap 8 µm

Loss and efficiency calculation

Overall efficiency chart calculated by loss analysis including the effects of

- viscosity change by pressure and
- elastic deformation of port plate

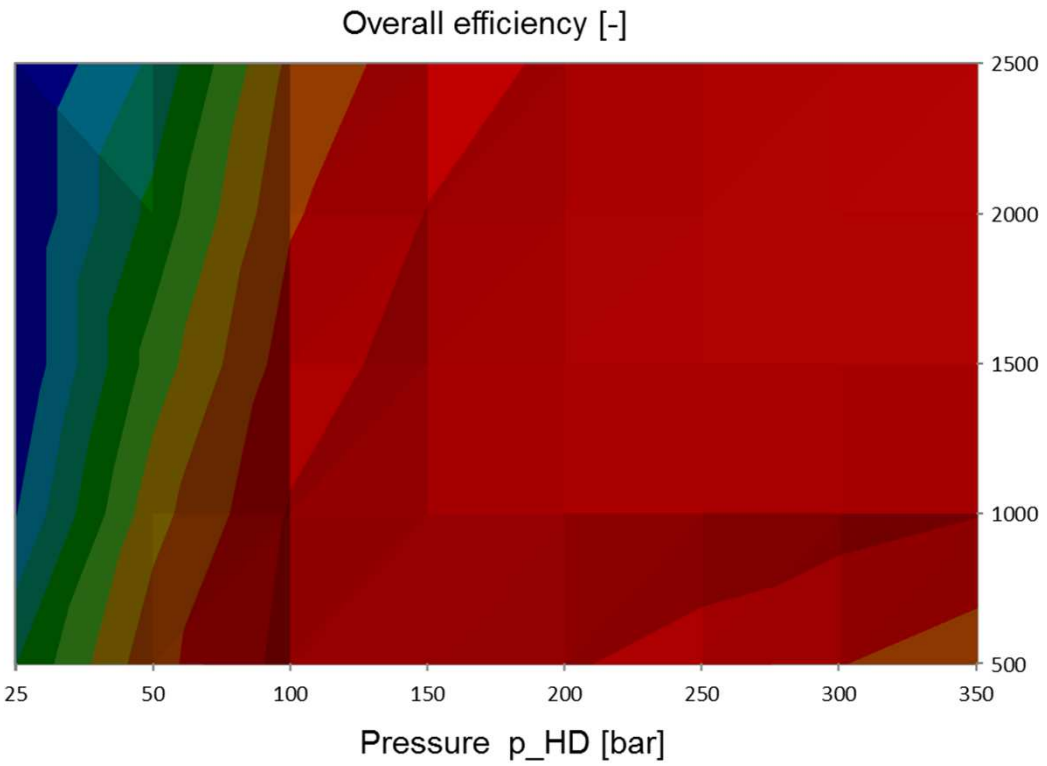


Loss and efficiency calculation

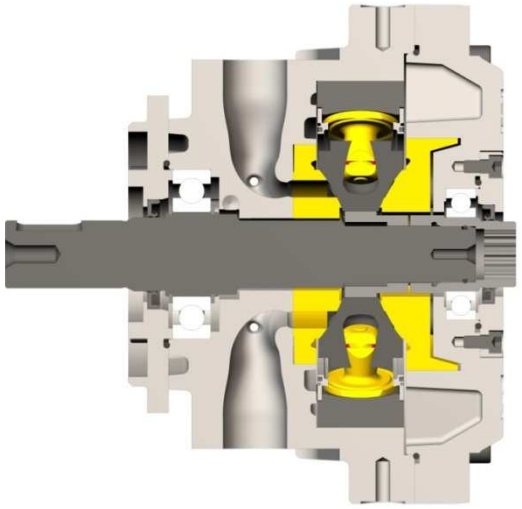
Overall efficiency chart calculated by loss analysis including the effects of

- viscosity change by pressure and
- elastic deformation of port plate

► targeted improve of design



viscosity 15 mm²/s
slipper gap 13 µm
port plate gap 7 µm



New concepts – science fiction

- Up to here, everything is well tested and validated
- From now, we ask you to follow us into the future
  - to „science fiction“

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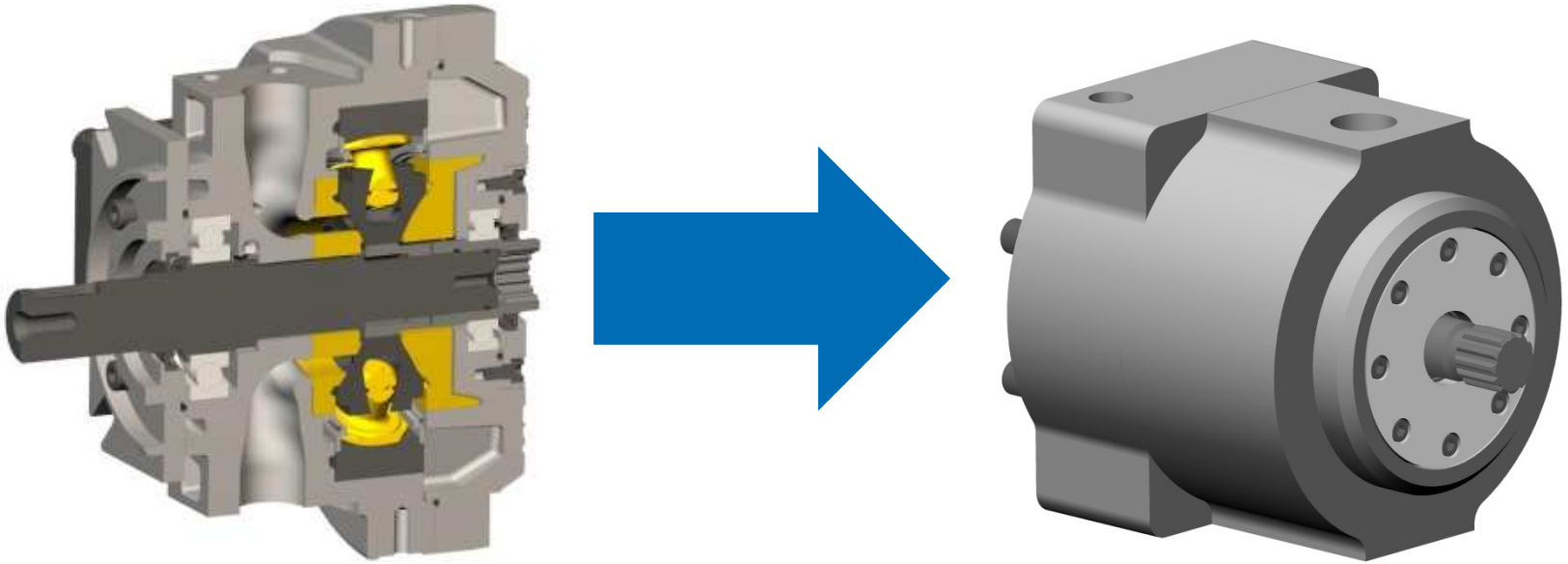
New concepts – science fiction

We will transfer the main features of the RAC radial piston machine to a novel axial piston type:

- Hydrostatic bearings
- Tilt pistons
- Piston sealing rings

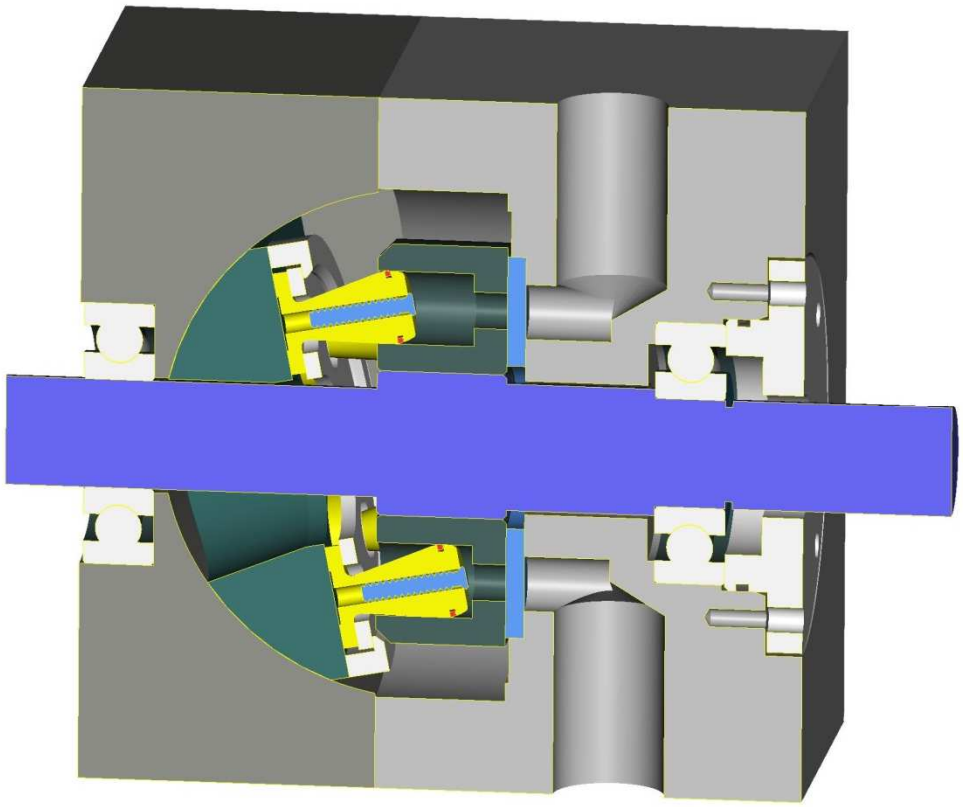


ATP axial tilt piston machine

Parts of the ATP machine:

- housing with shaft and swashplate
- port plate and cylinder barrel
- tilt piston
- downholder

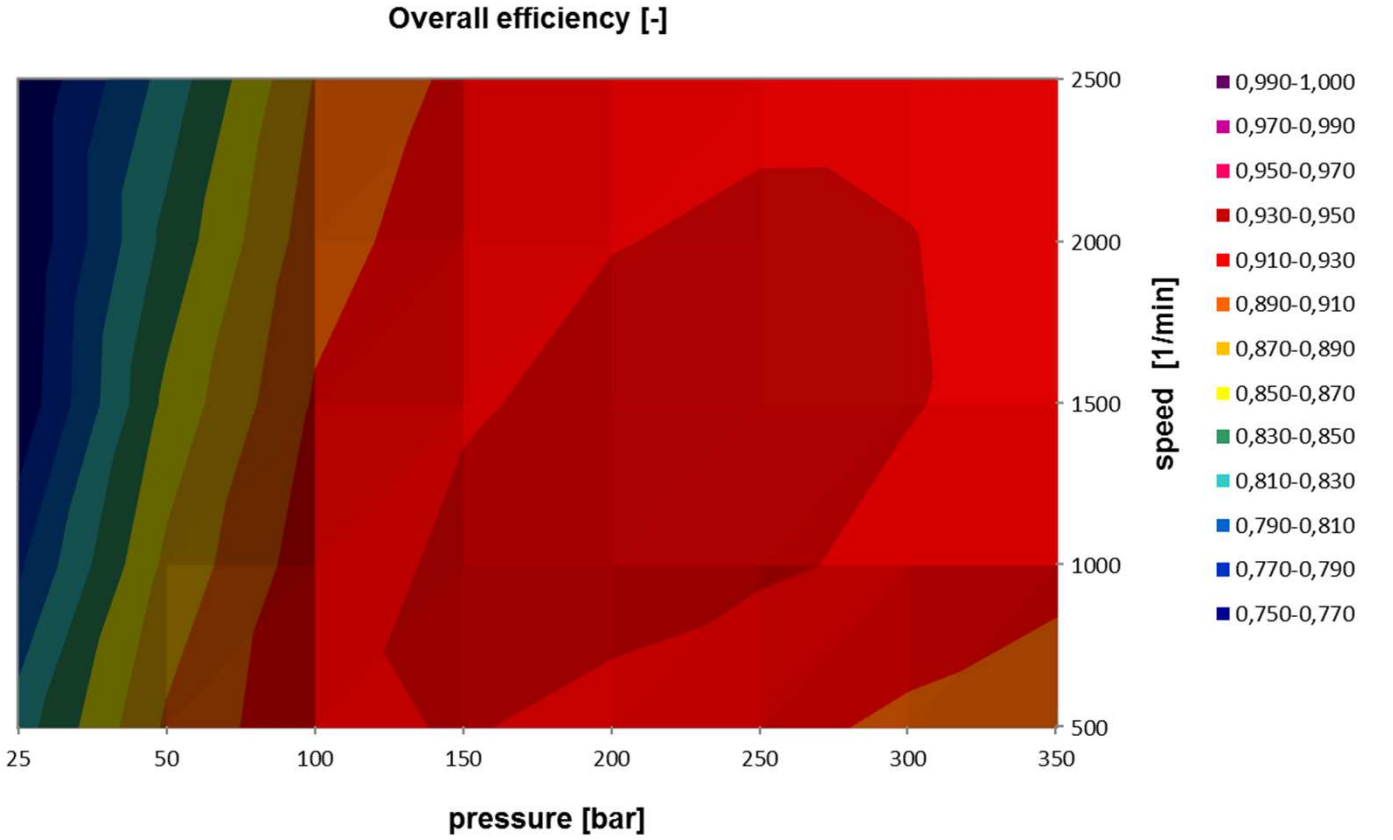
Based on the geometric data
the losses and efficiency can be
computed

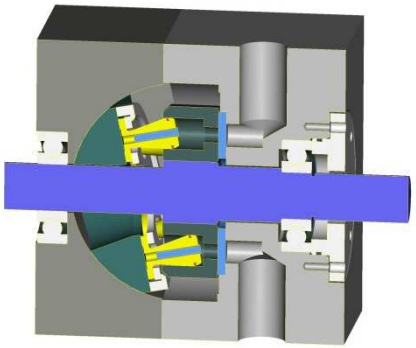


Efficiency calculation for ATP axial tilt piston machine

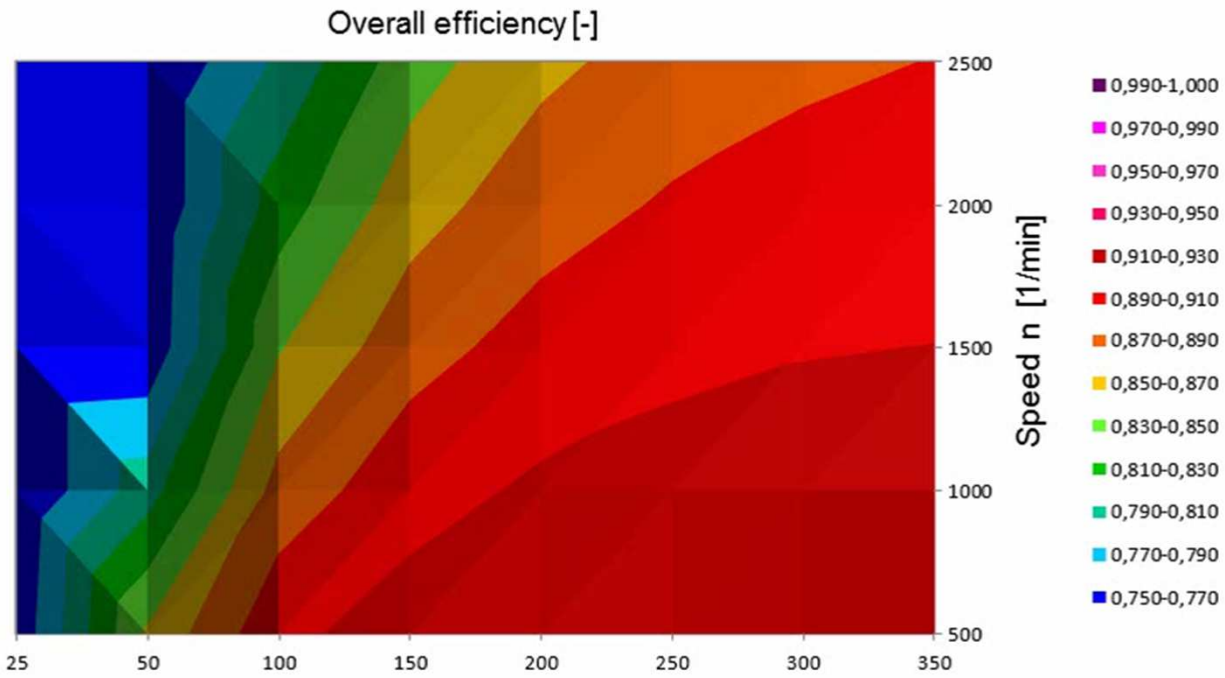
Displacement 40 cm^3 (pump mode)
viscosity 25 mm^2/s

port plate gap 8 µm
slipper gap 12µm

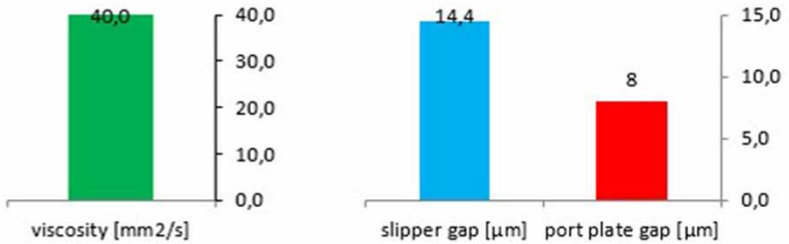


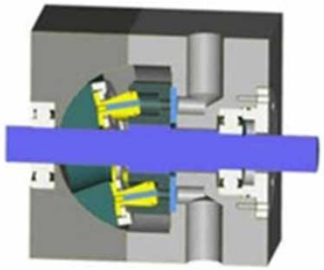


Change of efficiency with several parameters



VIDEO

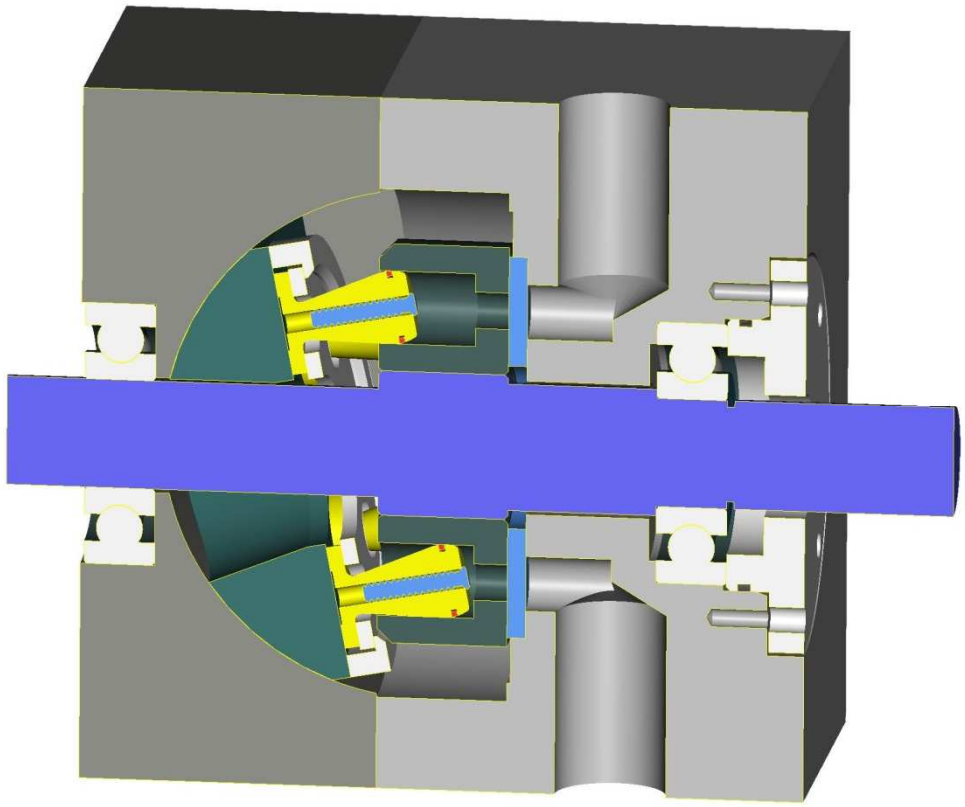




ATP axial tilt piston machine

Characteristics of the ATP machine:

- hydrostatic bearings for the main tribosystems
- usable for high pressure at low speed
- adaptable for low viscosity
- gap heigths can be adapted for optimum efficiency
- tilt piston and sealing are well proven in the RAC development
- easy manufacturing



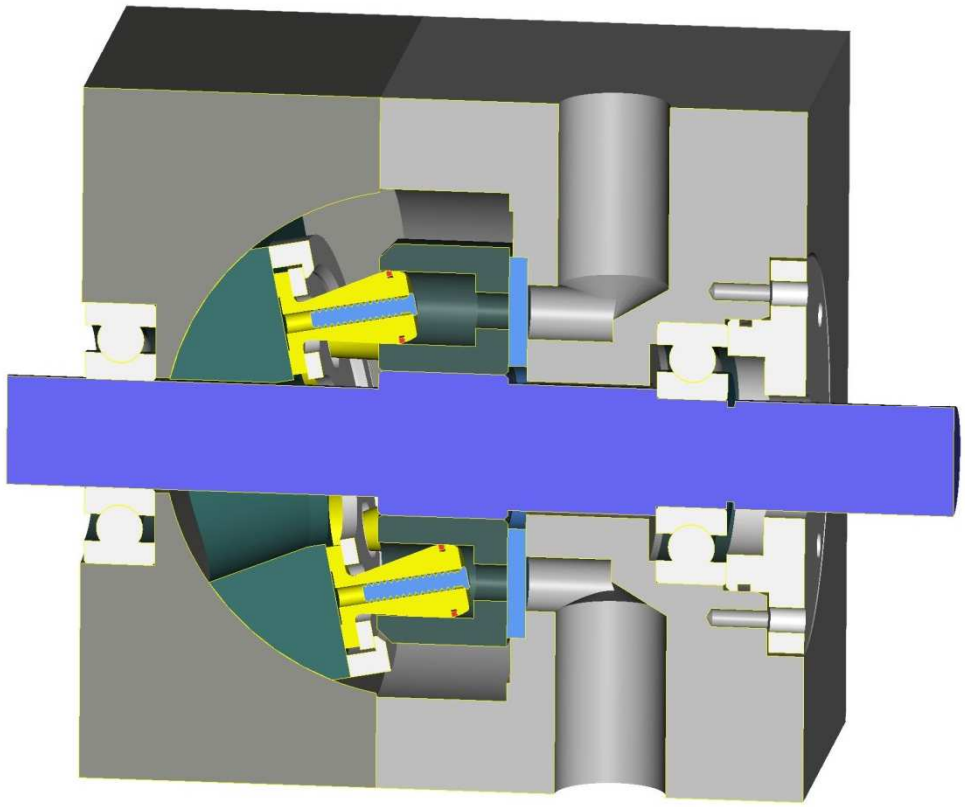
Efficiency by design

1	Basic ideas about energy dissipation in hydrostatic machines
2	First step: Eliminate locations of dissipation (as far as possible)
3	Second step: Replace mixed friction by Newtonian friction
4	Third step: Setup of a loss and efficiency calculation program
5	Concept of a novel axial tilt piston machine
6	Conclusion

Conclusion

Predefined tribological systems enable

- computable properties of sliding contacts
- targeted adaption to the operating condition
- **reduction of development time**



Thank you for your attention!

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