UNUSUAL ASPECTS TO BE CONSIDERED IN THE SIMULATION OF POSITIVE DISPLACEMENT MACHINES

Massimo Rundo

POLITECNICO DI TORINO
Dipartimento Energia

Fluid Power Research Laboratory

Global Fluid Power Society

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Summary

3 EXAMPLES ANALYZED

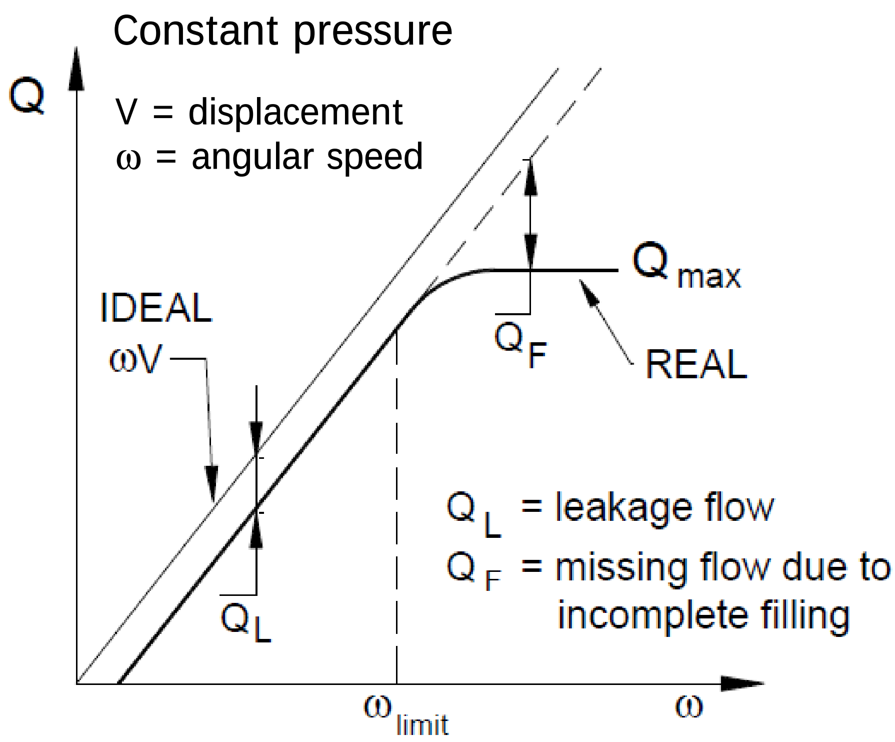
- **Centrifugal force on the oil in the variable chambers in conditions of incomplete filling**

- **Elastic deformation of the cover/port plate**
  Positive or negative effects on:
  - **volumetric efficiency**
  - **pressure ripple**

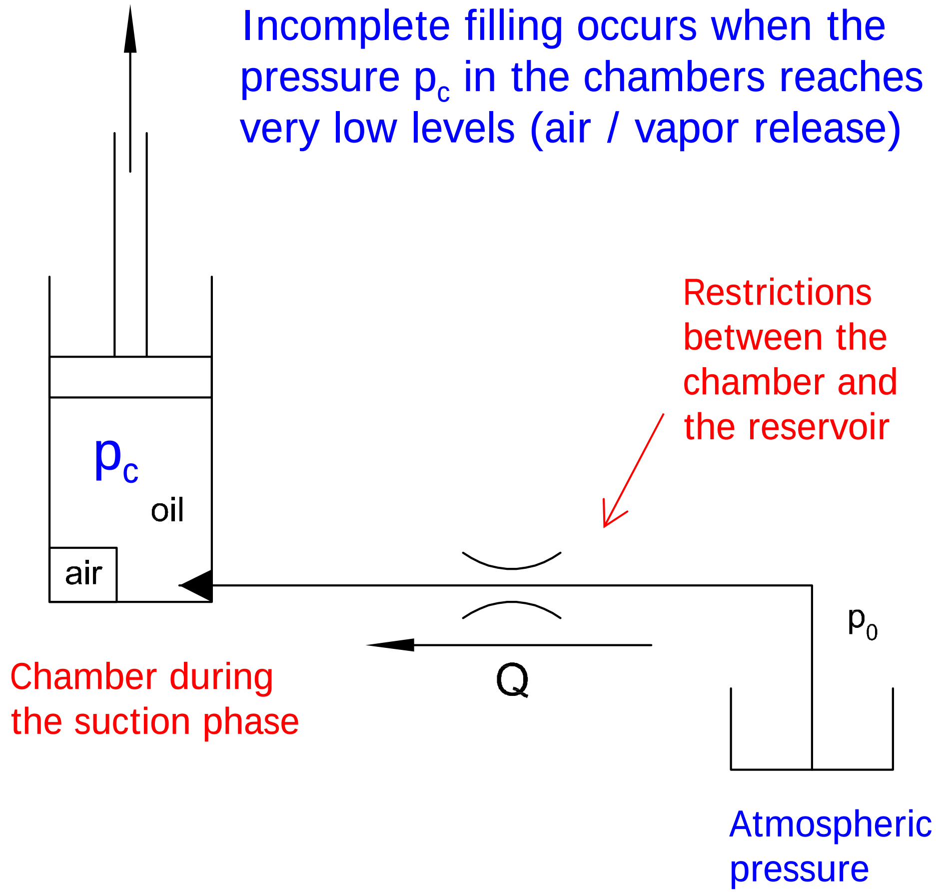
- **Elastic deformation of the stator**
  Influence on the pump displacement

Incomplete filling

In a positive displacement pump, the real flow rate **Q** differs from the theoretical value due to the leakages and, at high speed, to the incomplete filling

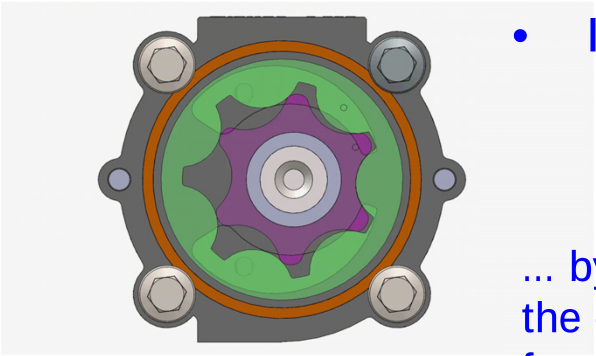


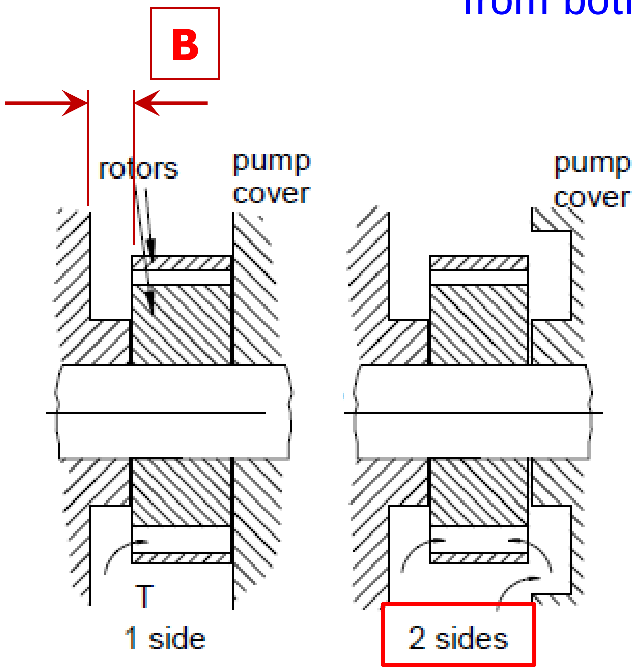
Incomplete filling occurs when the pressure p_c in the chambers reaches very low levels (air / vapor release)



Common remedies for improving the filling

- Reduction of the pressure drop in the suction pipe
- Increment of the chambers' flow areas …

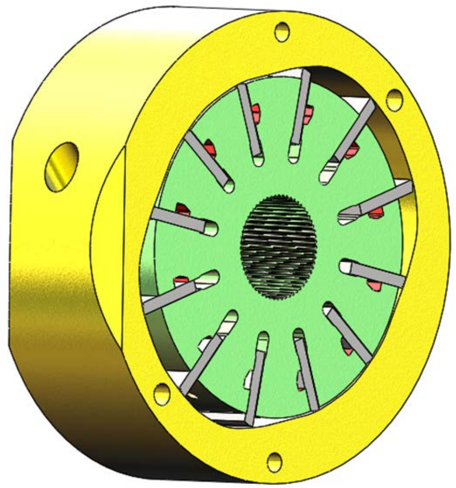


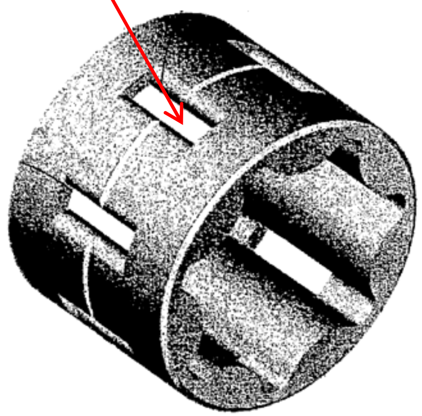


… by feeding the chamber from both sides

… by feeding radially through holes, slots, cuttings

Vane pump

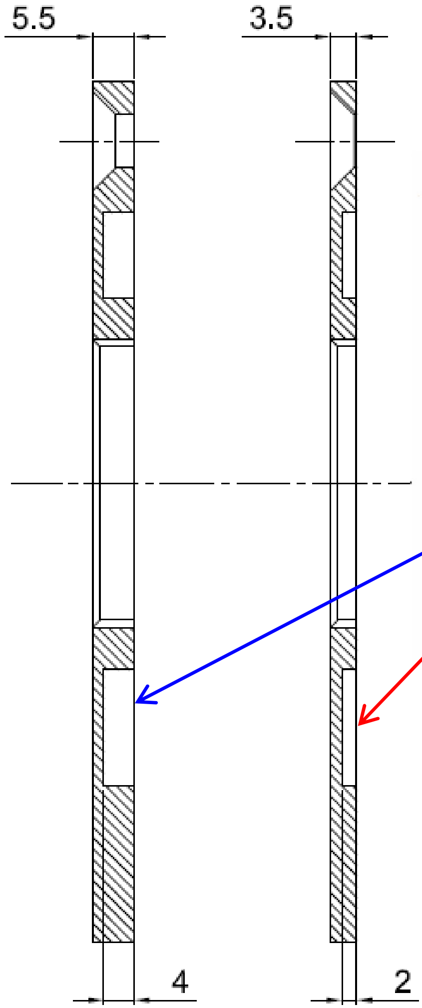




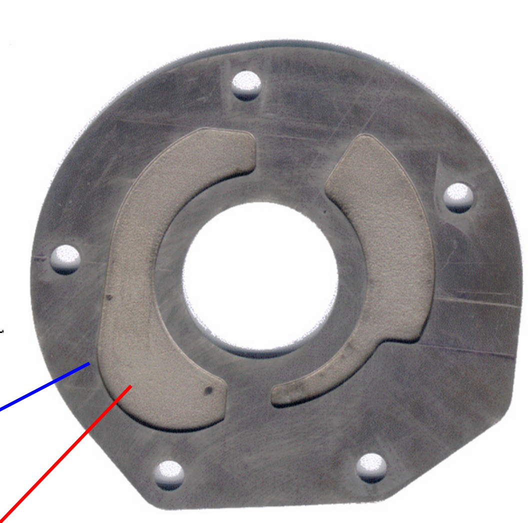
Outer rotor of internal gear pump

Not always these solutions are beneficial !

Former «unexplained» experience on gerotor



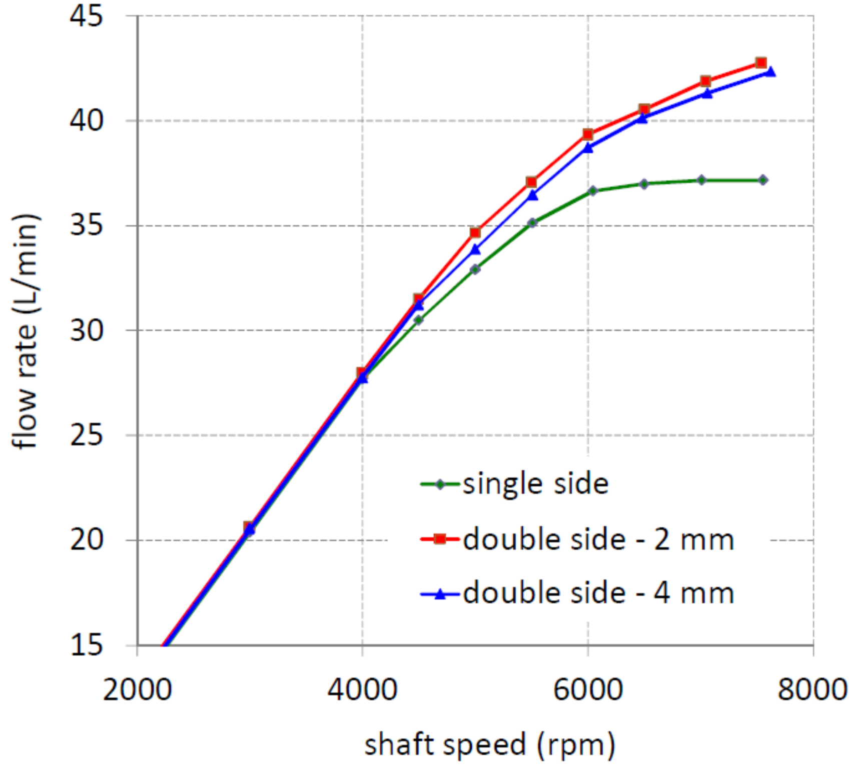
Modified cover for feeding the gears from both sides



2 values of depth tested

- 2 mm
- 4 mm

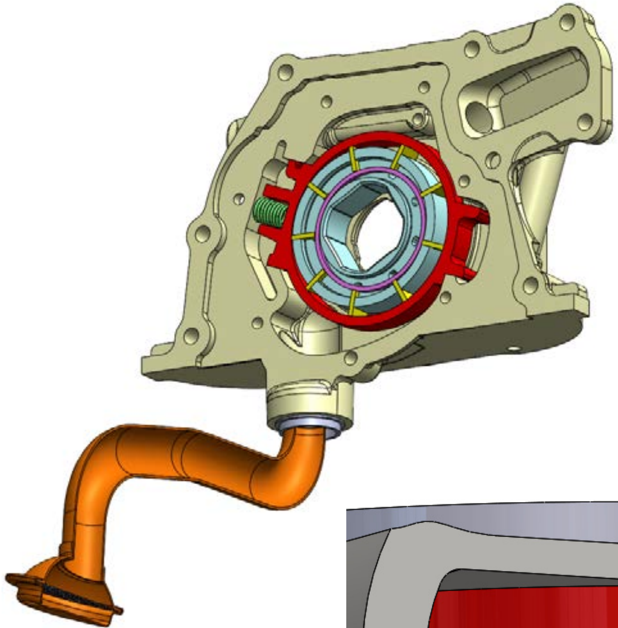
Experimental flow-speed curves (23 February 1999)

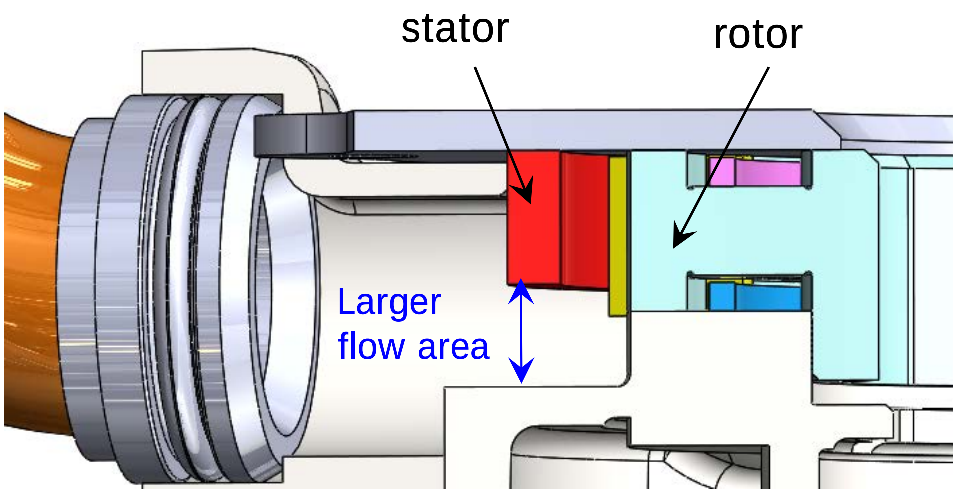


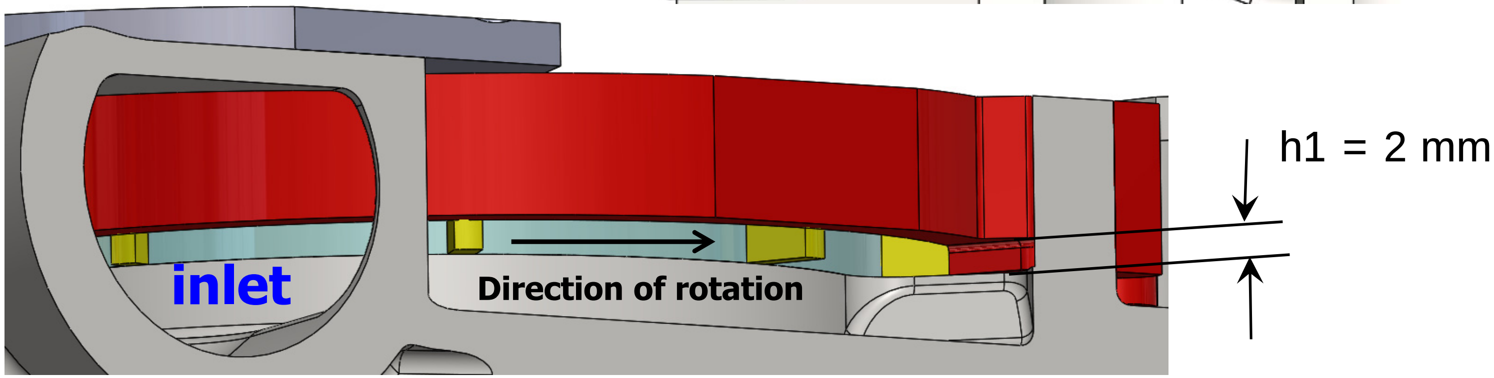
From 2 to 4 mm → worsening (?!?)

Similar experience on a vane pump

Baseline configuration (1): single side feeding with improved flow area

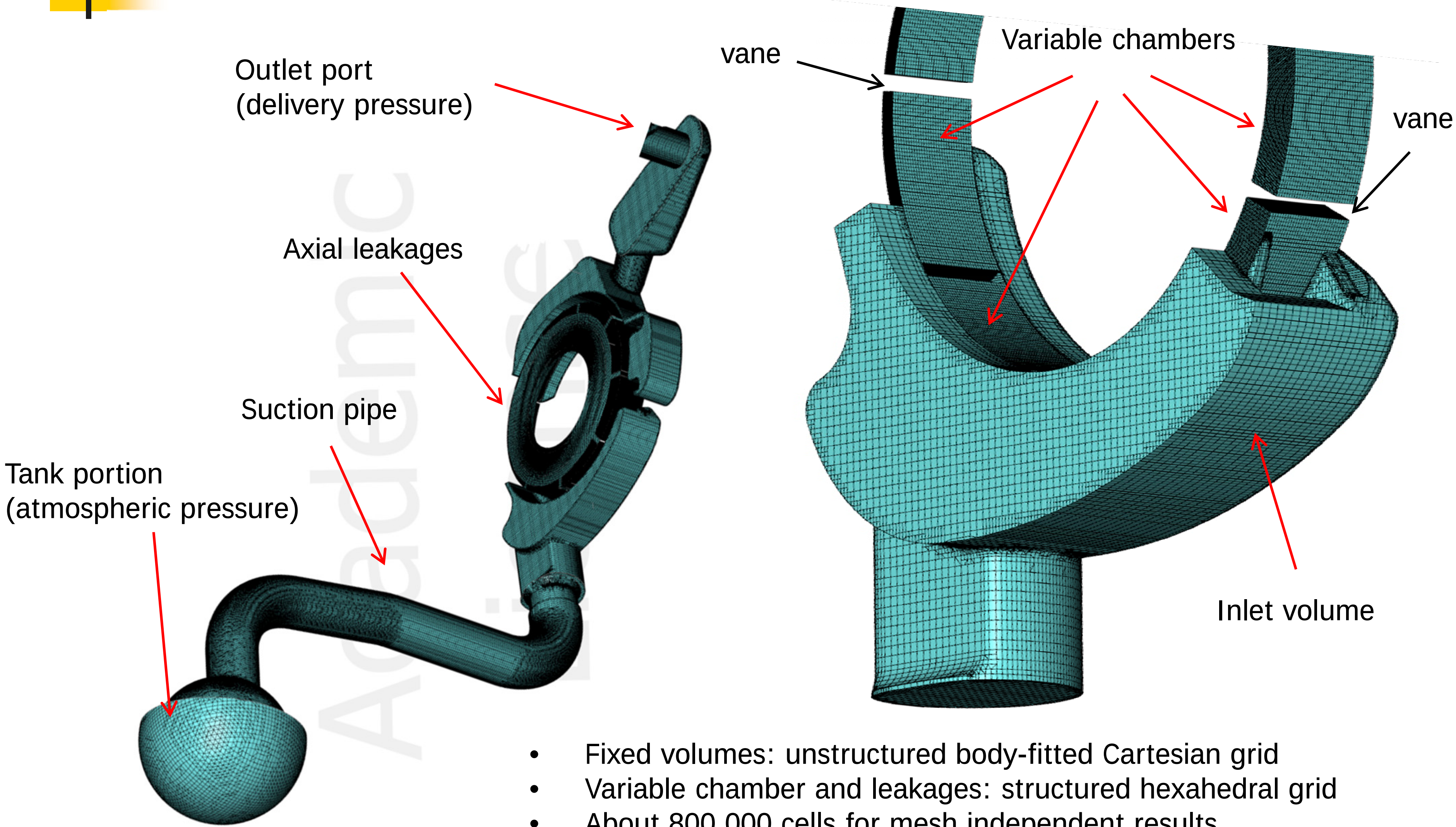






Experimental tests and CFD simulations have demonstrated the effectiveness of the milling h1

CFD model of the reference pump



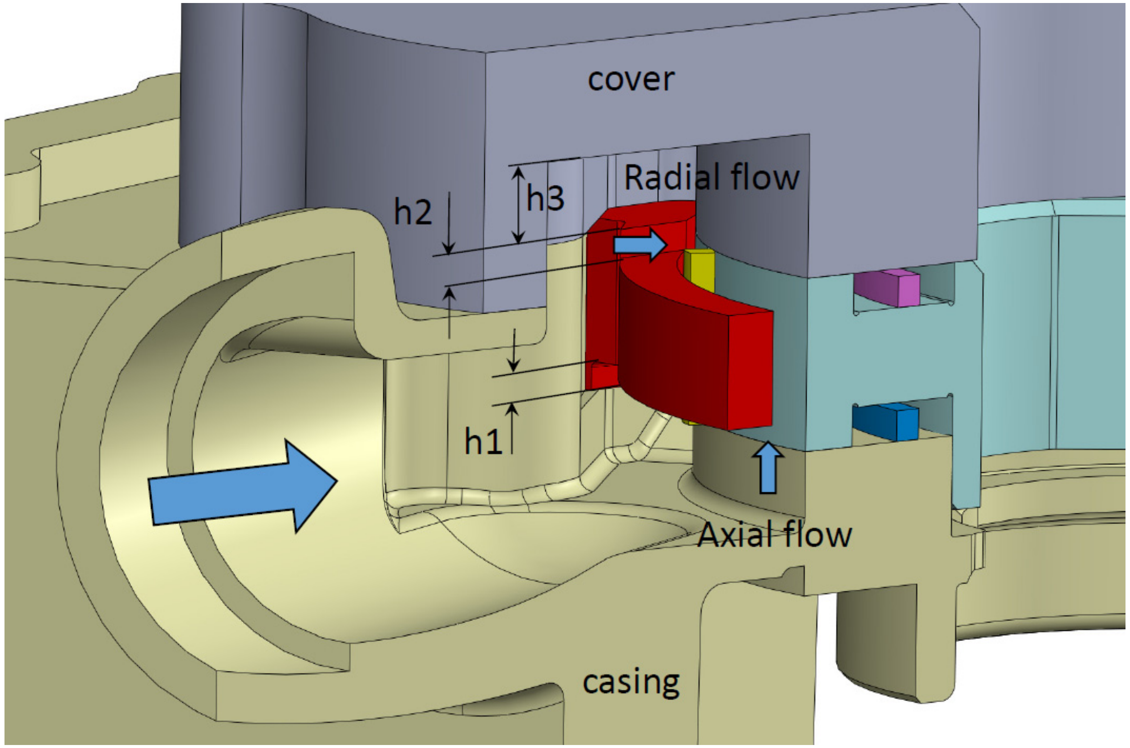
- Fixed volumes: unstructured body-fitted Cartesian grid
- Variable chamber and leakages: structured hexahedral grid
- About 800 000 cells for mesh independent results

Five configurations analyzed

CFD simulations at :
5200 rpm – displacement 55%

h1 = 2 mm

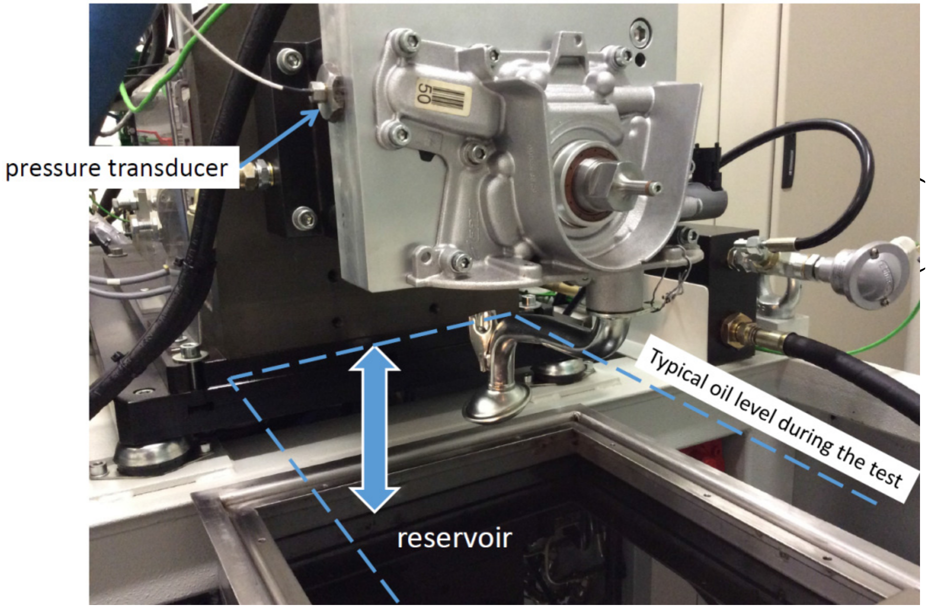
Config.	h2 (mm)	h3 (mm)	Flow rate (L/min)
1	0	0	40.1
2	1	0	37.4
3	2	0	33.2
4	0	5	37.4
5	2	5	35.4



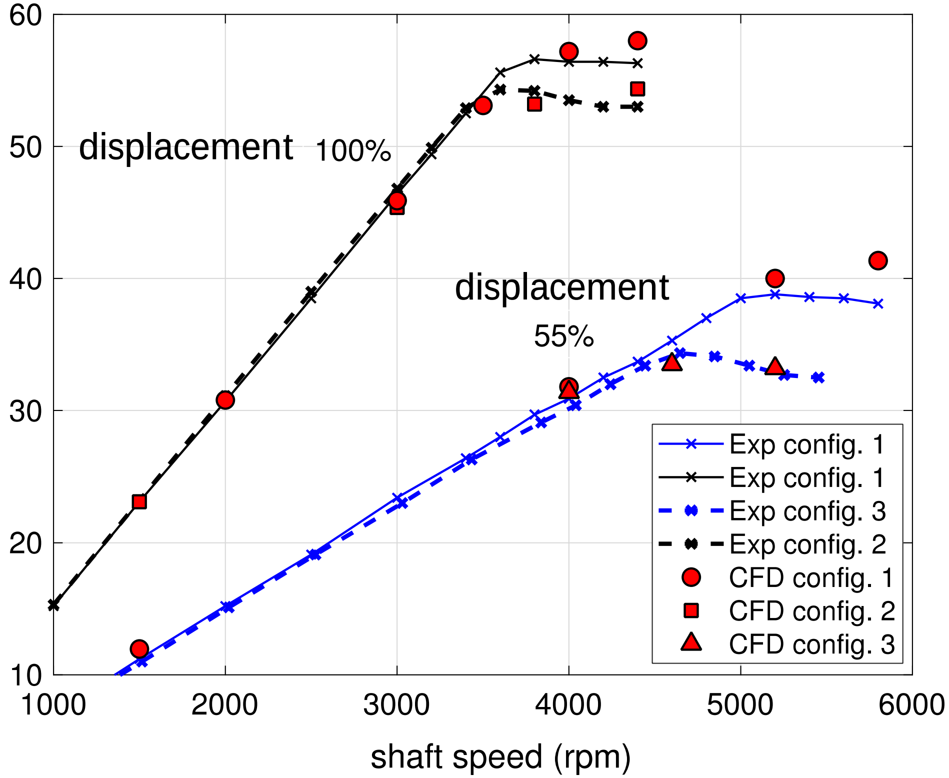
With 0D model any additional flow area causes the increment of the flow rate

The 3D model gives opposite results (higher area = lower flow rate)

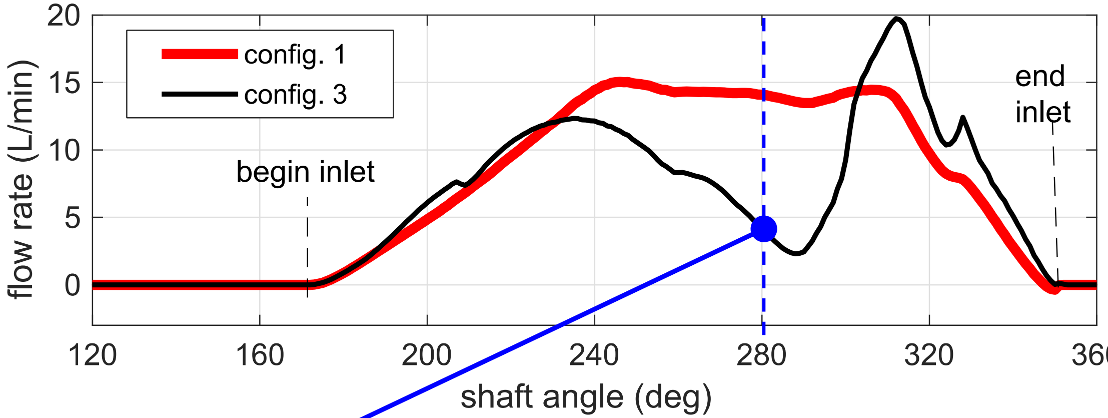
Model validation



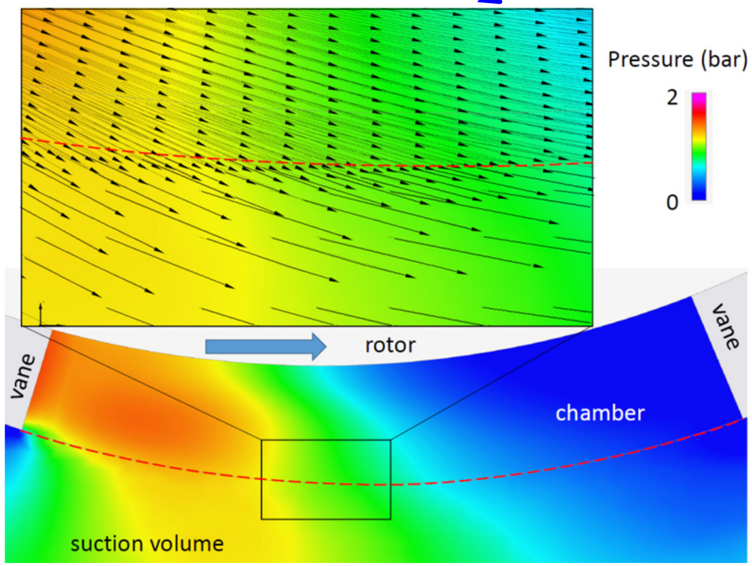
Constant delivery pressure (3 bar)
and constant displacement



Flow rate entering a chamber: configs 1 & 3

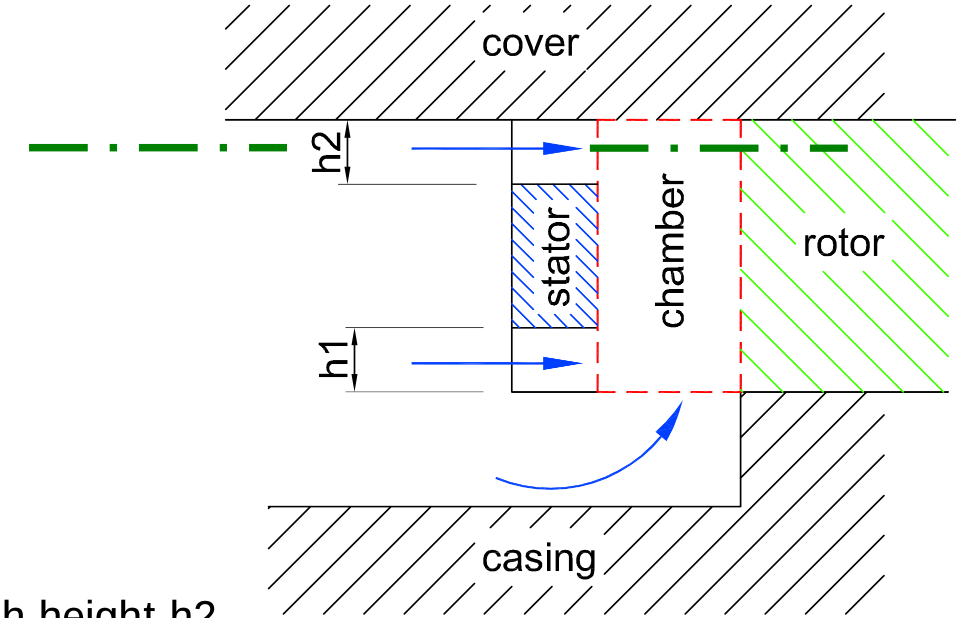


(5200 rpm – 55% displ.)

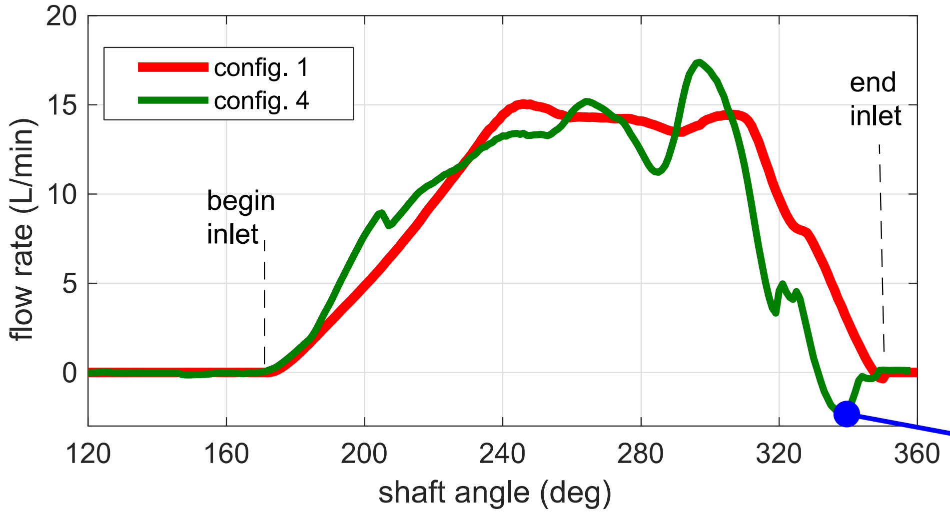


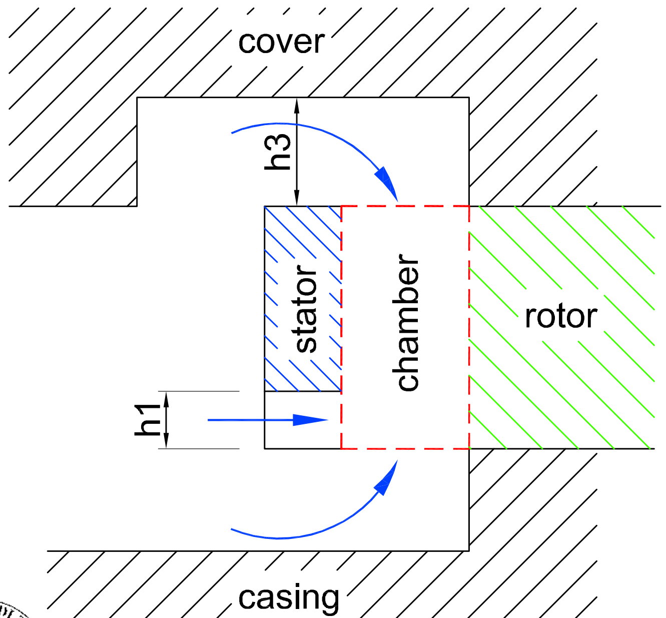
Cut plot in the middle of the milling with height h2

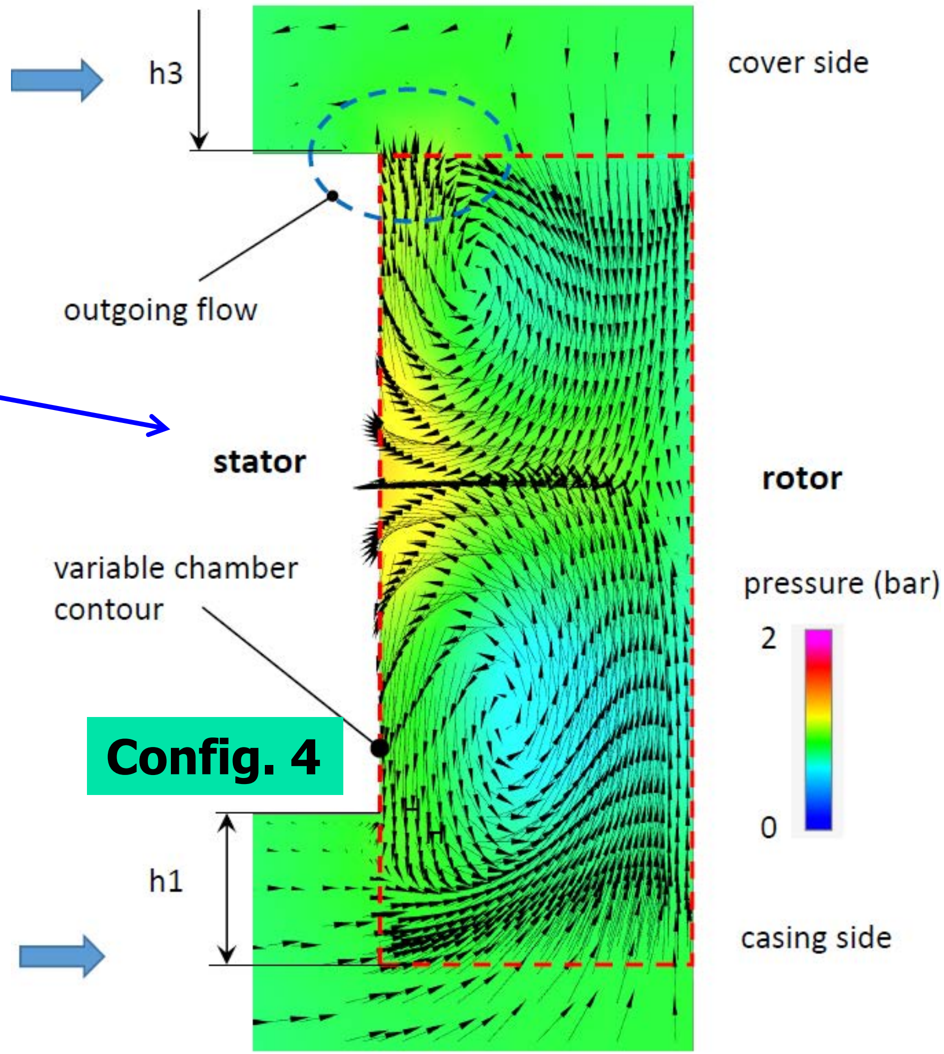
Config. 3



Flow rate entering a chamber: configs 1 & 4







Some intermediate remarks

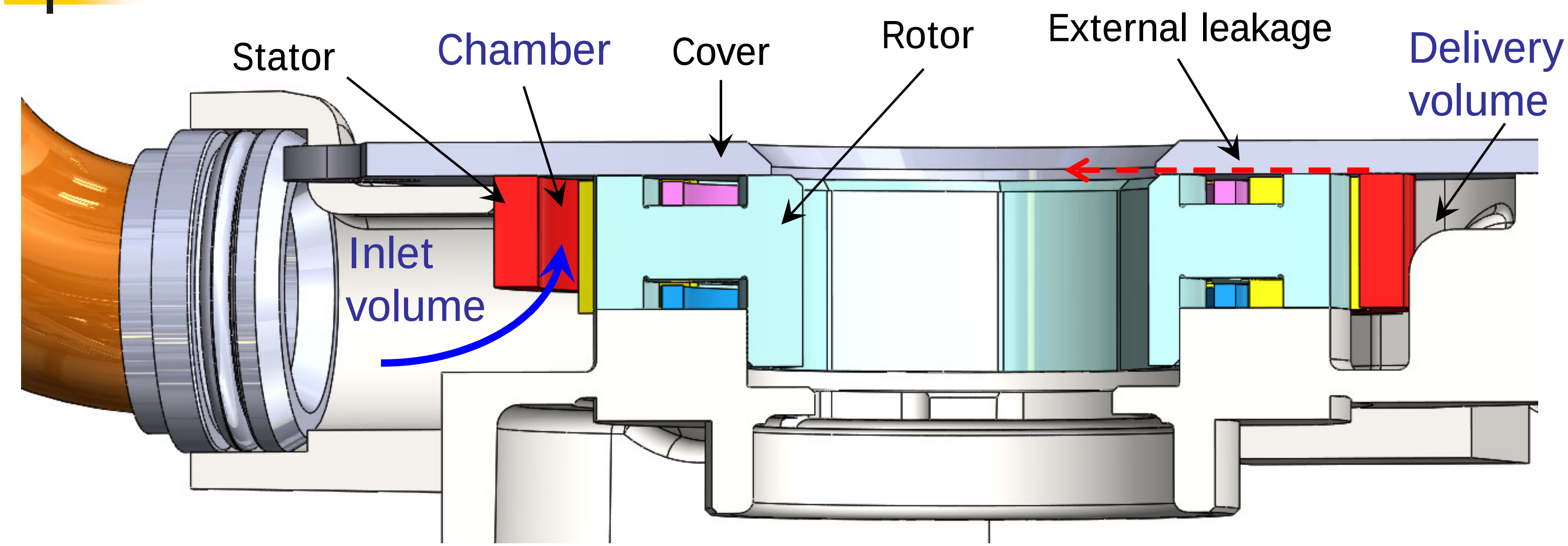
- In pumps with high ratio thickness/diameter both double feeding and radial feeding through slot in the stator are beneficial (as expected)

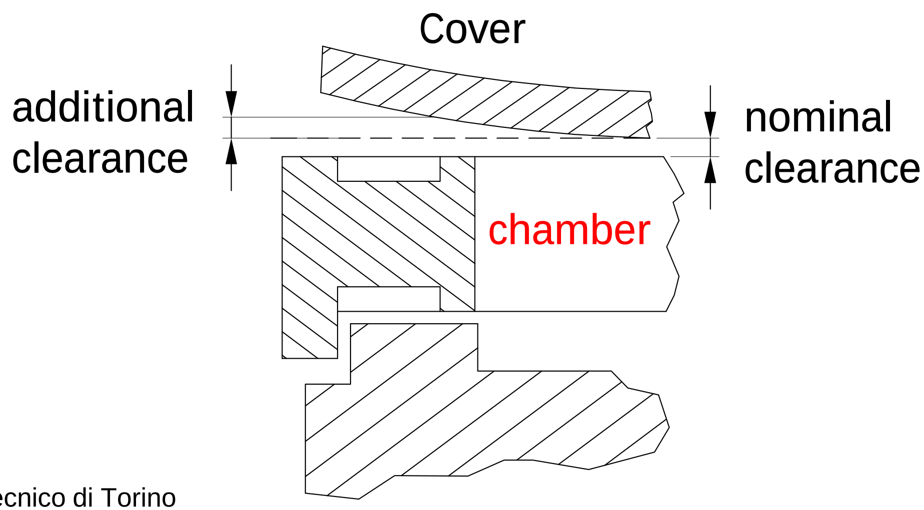
- In pumps with low ratio thickness/diameter the effect of centrifugal force is predominant above all at low displacement

→ Unusual aspect to be considered:

centrifugal force in the variable chambers

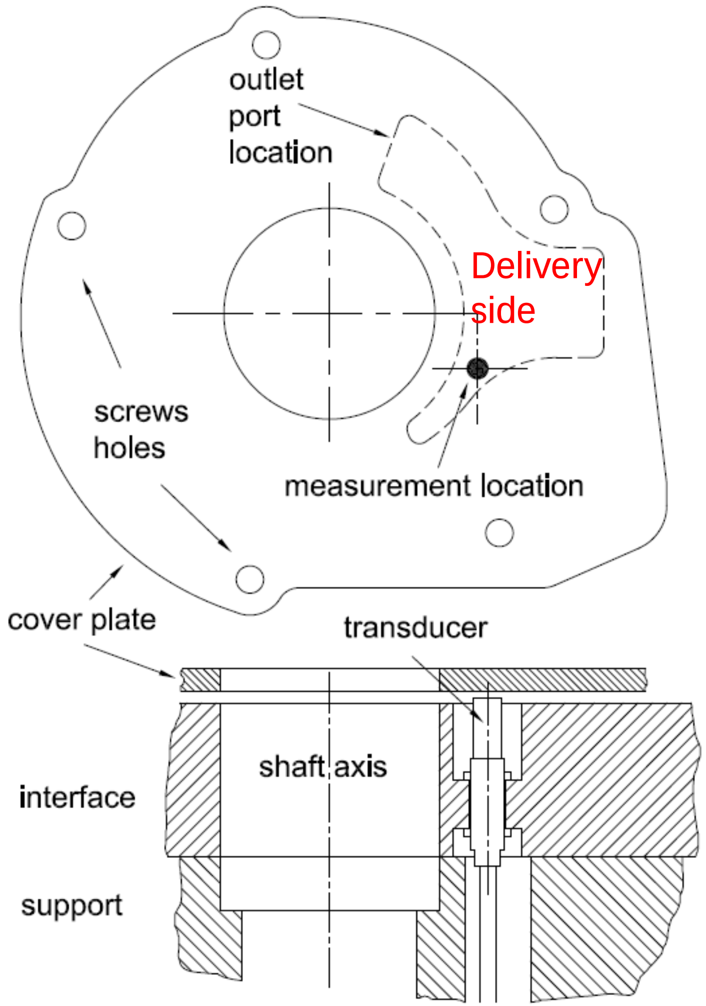
Influence of cover deformation



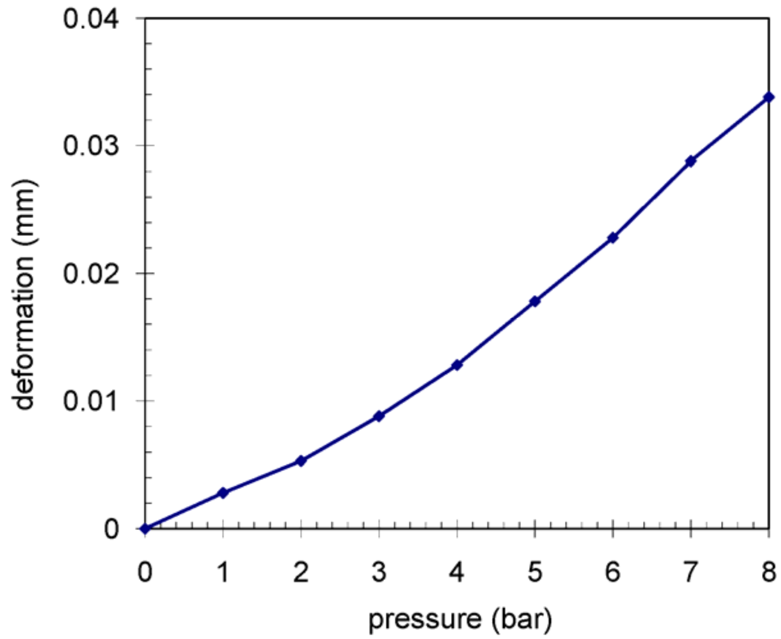


Is it so important ?

Measurement of the additional gap



Output of contactless displacement transducer



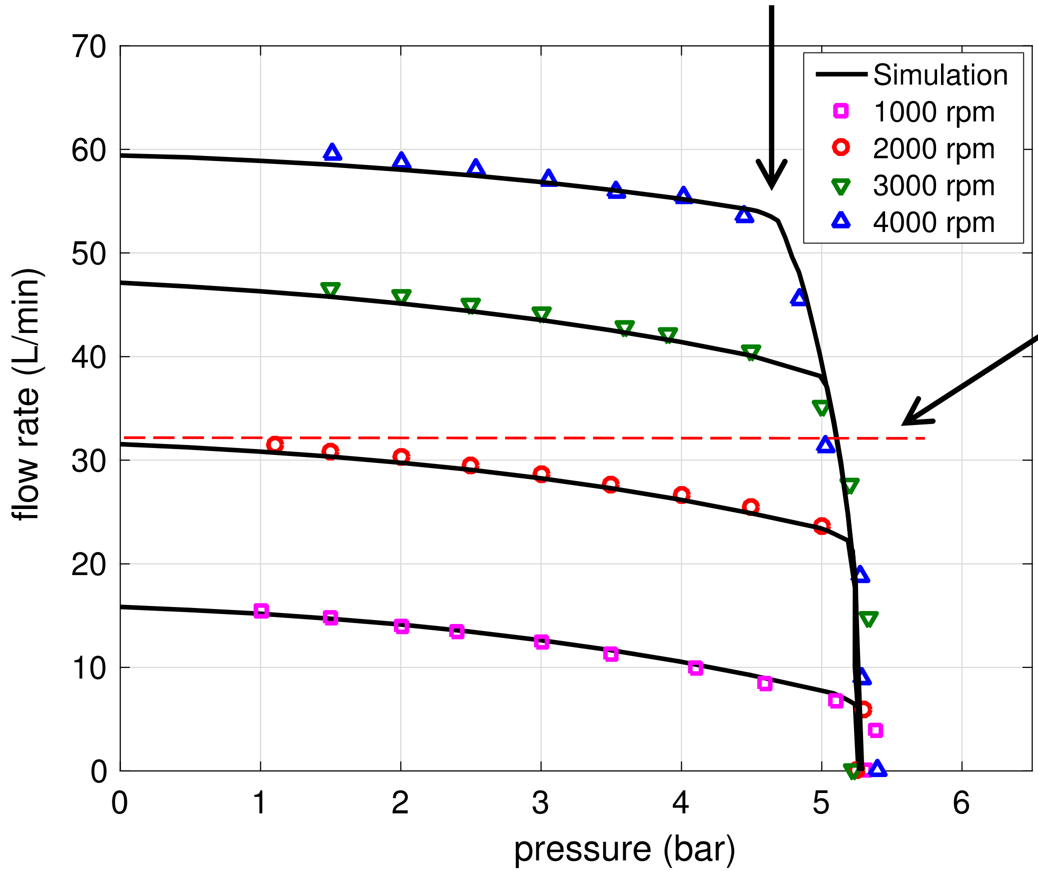
Nominal gap 20-30 μm
Additional gap 8 bar 35 μm

-> external leakage = 10 times higher !!

Steady-state flow-pressure curves

0D model with coefficient tuned on FEM

Intervention displacement control



Oil temperature: 120 °C

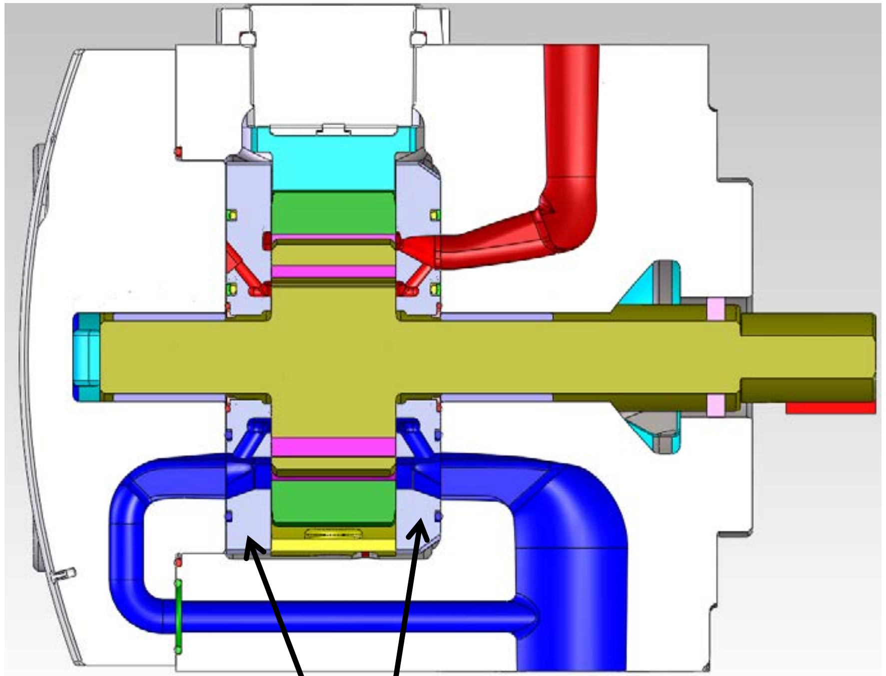
Progressive reduction of flow area of the load valve

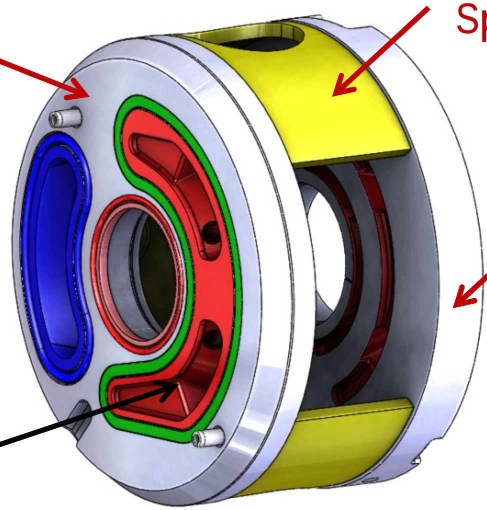
Theoretical flow rate

Non-linear flow-pressure characteristic due to the variable clearance (deformation of the cover)

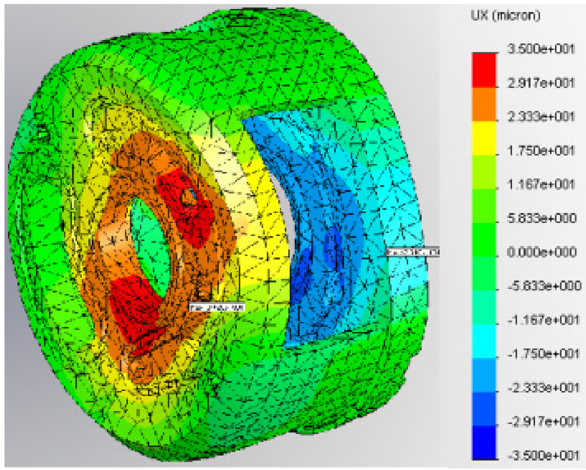
$$Q_{leak} = \frac{b\left(h + k \cdot p\right)^3}{12\mu L} p$$

The case of high pressure vane pump

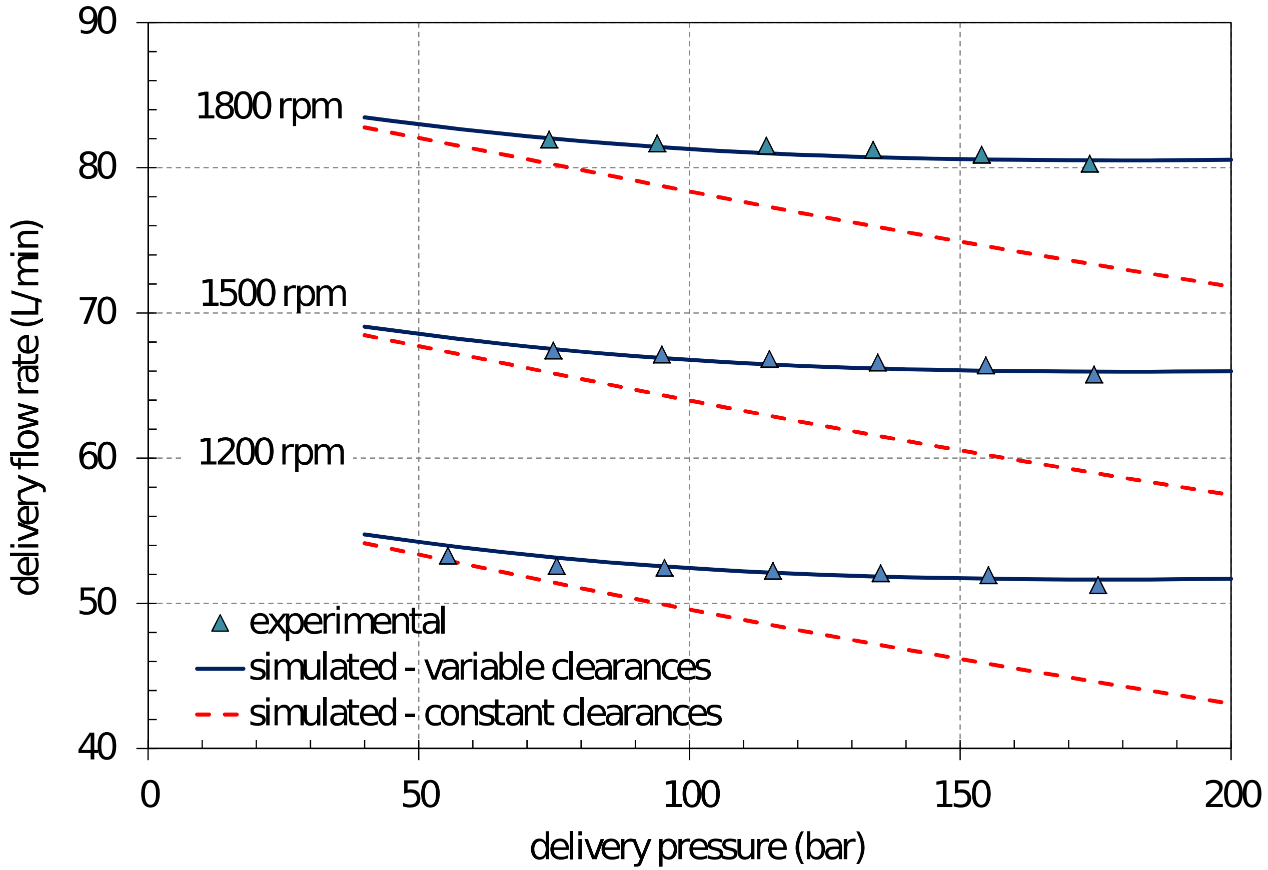




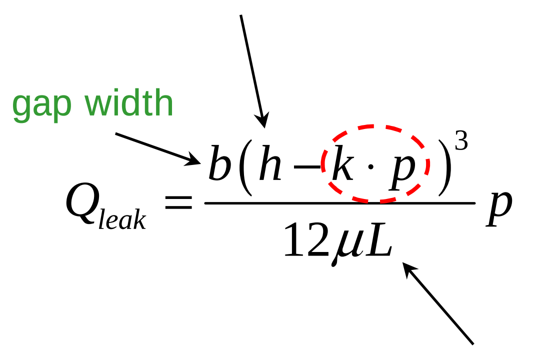
Deformation field at 200 bar



… and the effect of the port plate deformation



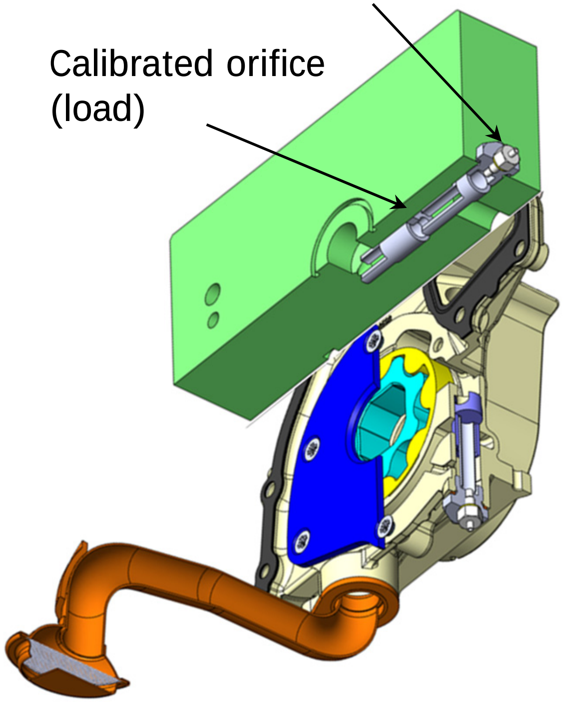
Non-linear flow-pressure characteristic
due to the variable clearance
(deformation of the port plate)

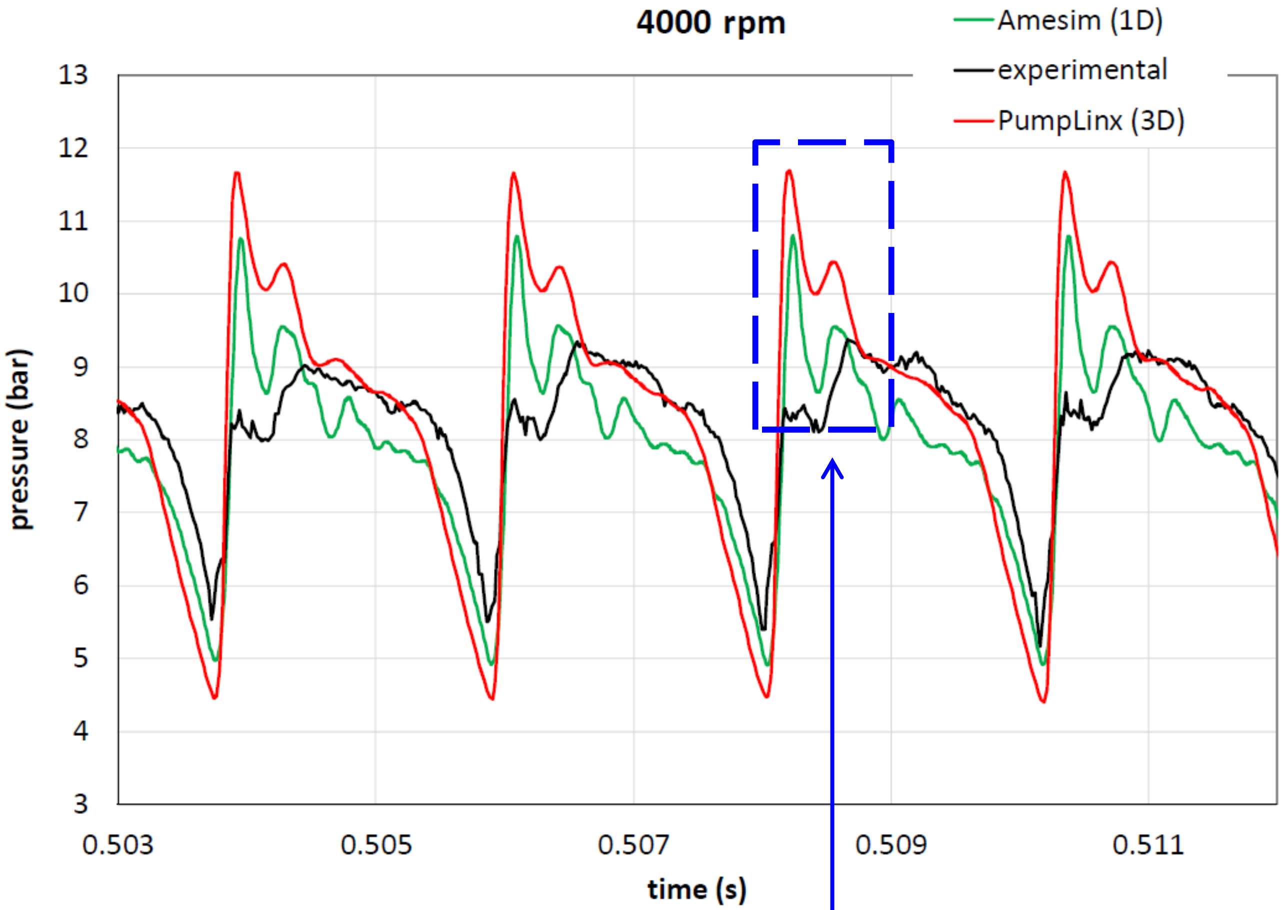


$$Q_{leak} = \frac{b\left(h - k \cdot p\right)^3}{12\mu L} p$$

Effects on the pressure ripple (gerotor)

Simplified "short" circuit for validating the pressure ripple

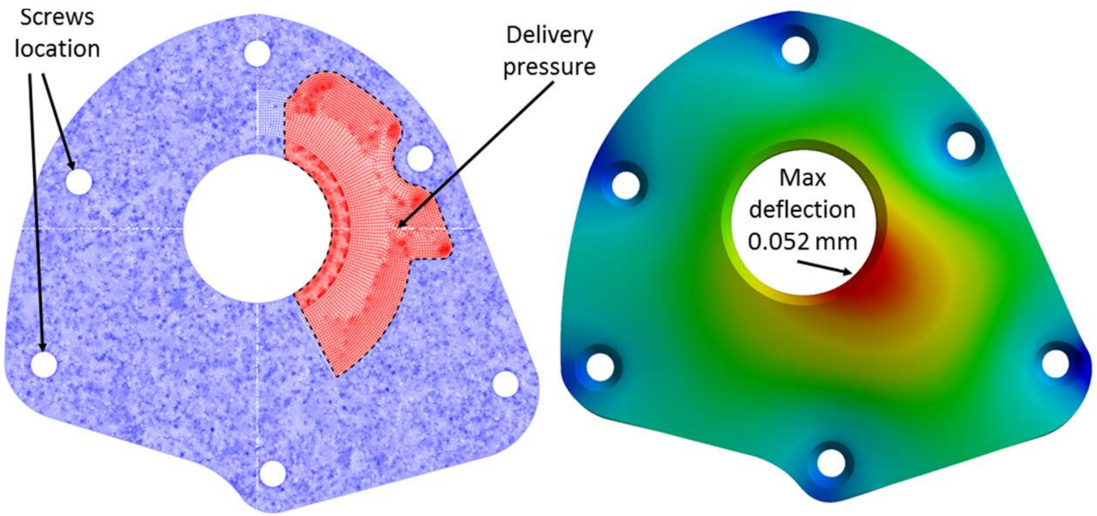


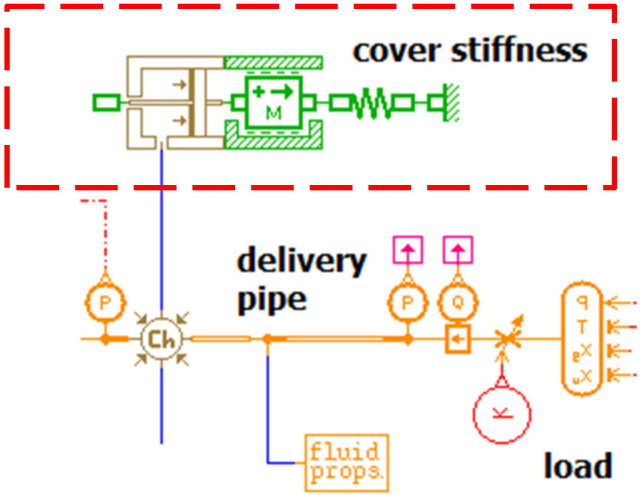


- 1D vs. 3D: very similar shape
- Exp. vs. sim. the pressure peak is missing

Model with deformable delivery volume

Deformation field $\delta(x,y)$





Increment of delivery volume

$$\Delta V = \int_S \delta dS$$

Equivalent spring accumulator with stiffness k_{eq}

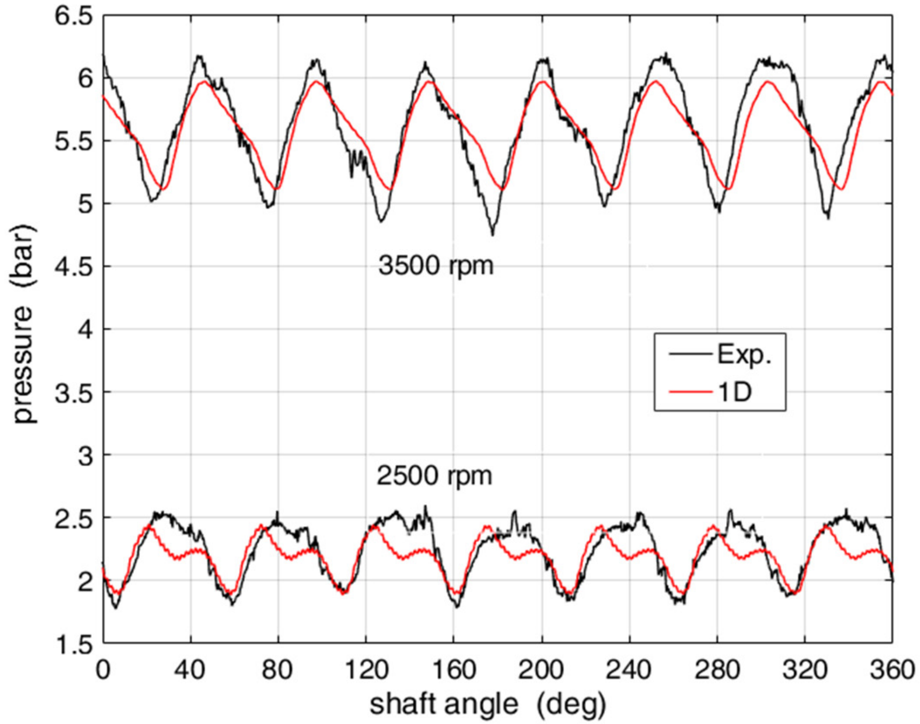
$$F = k_{eq}\Delta x = pS$$

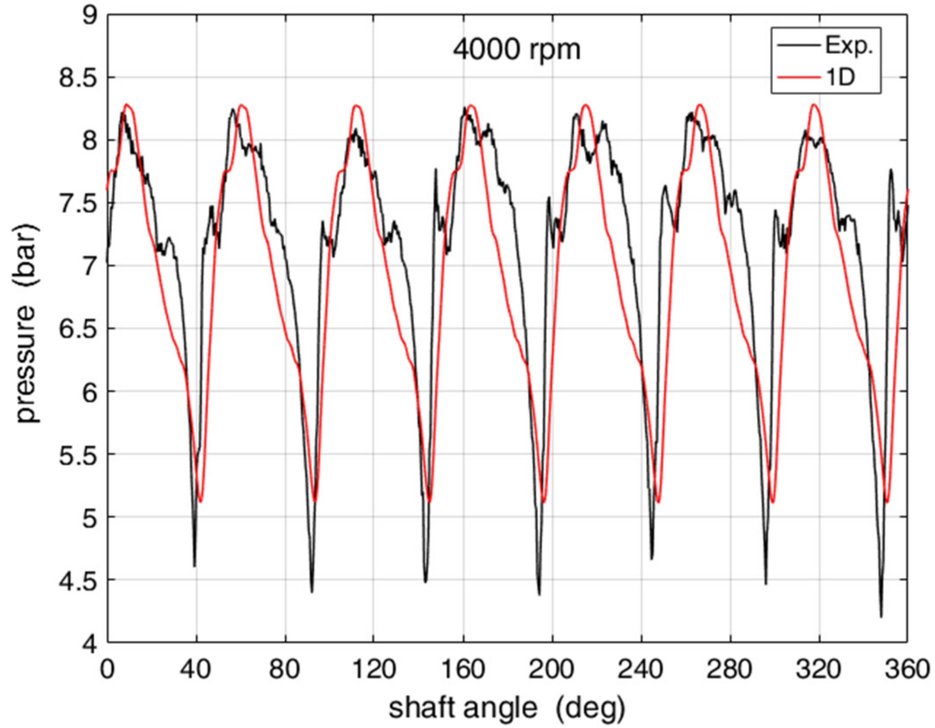
$$k_{eq} = \frac{p \cdot S^2}{\Delta V}$$

p [bar]	ΔV [mm³]	k_{eq} [kN/mm]
3	18.55	54.10
5	30.09	58.02
8.2	49.70	55.11

Improvement of the model

The peak has disappeared

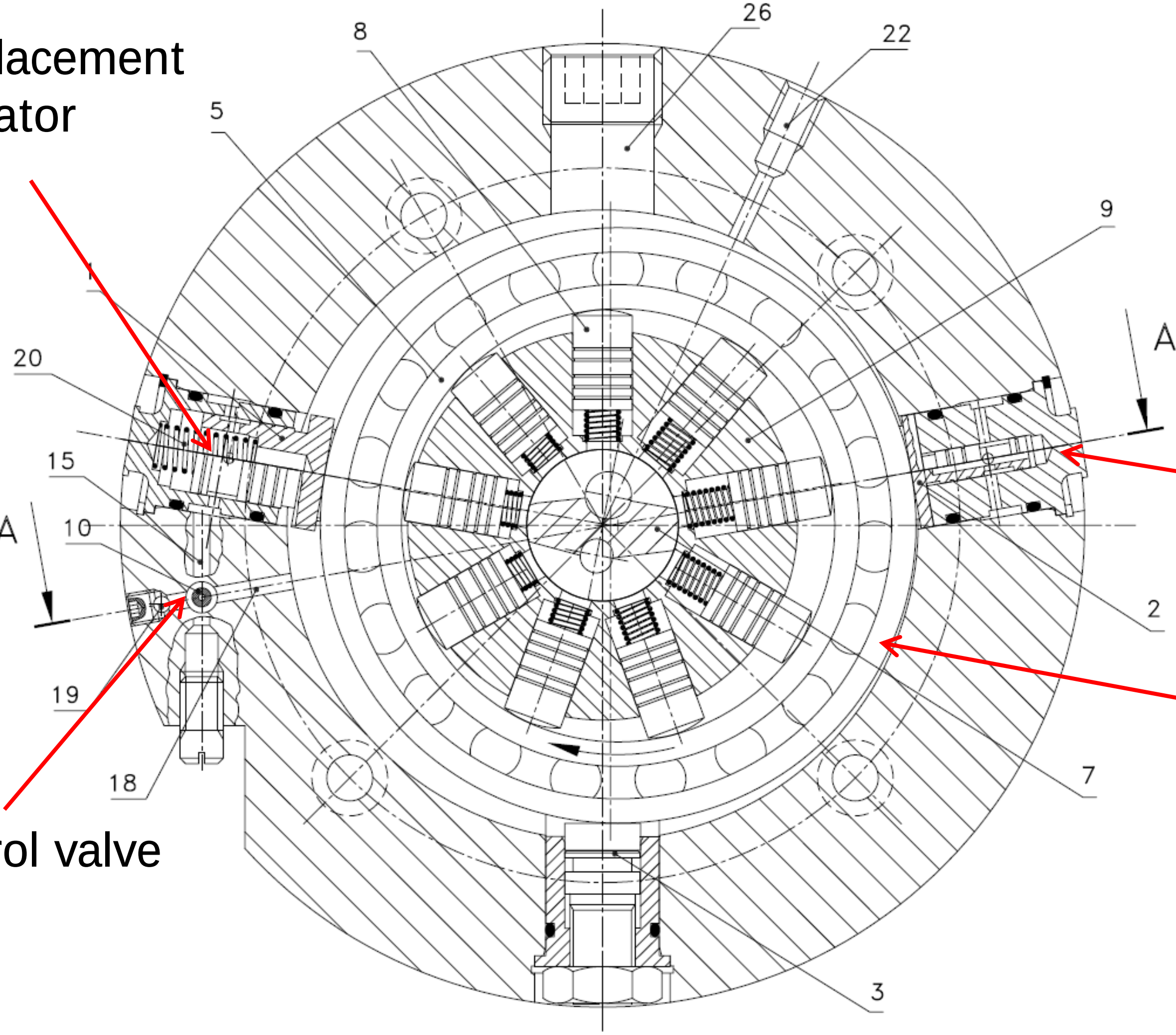




→ Unusual aspect to be considered: **cover pulsation**

The case of radial piston pump prototype

Displacement actuator



Displacement 4.53 cc/rev (accurately measured !)

Max pressure 30 bar

Contrasting actuator

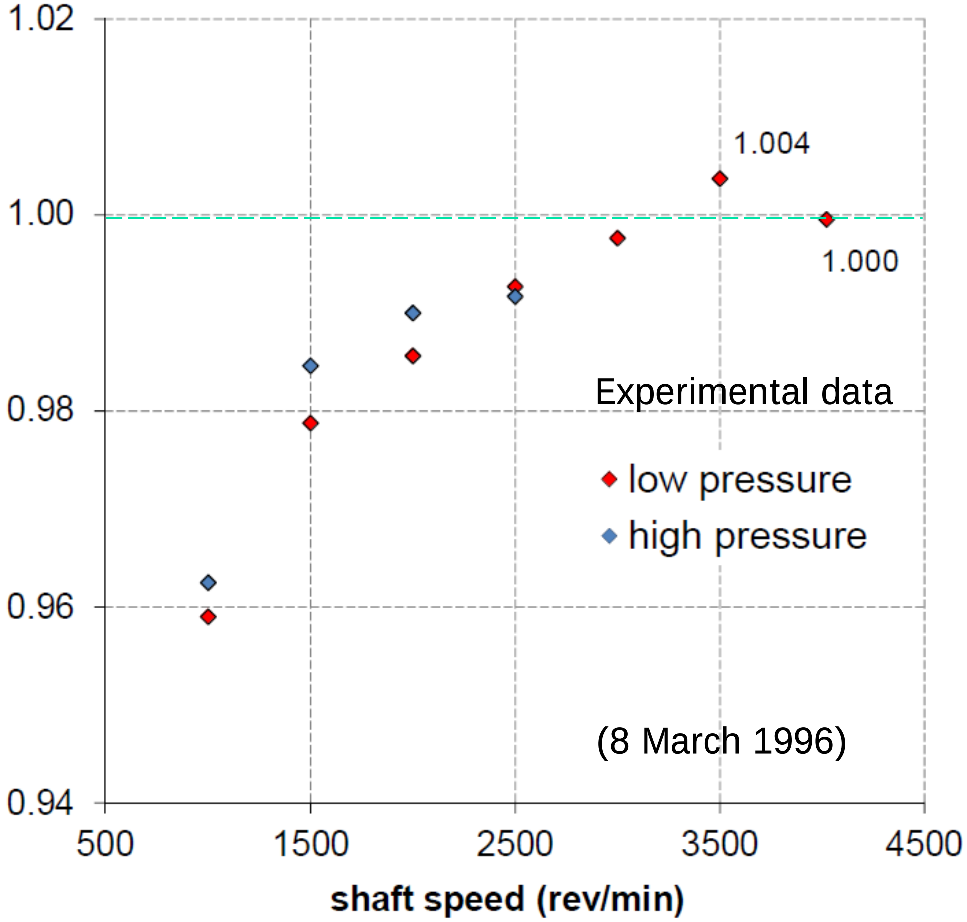
Commercial roller bearing used as stator

Control valve

Topic of the presenter's thesis (1996)

Very high (too much!) volumetric efficiency

Volumetric efficiency at constant pressure, temperature and displacement

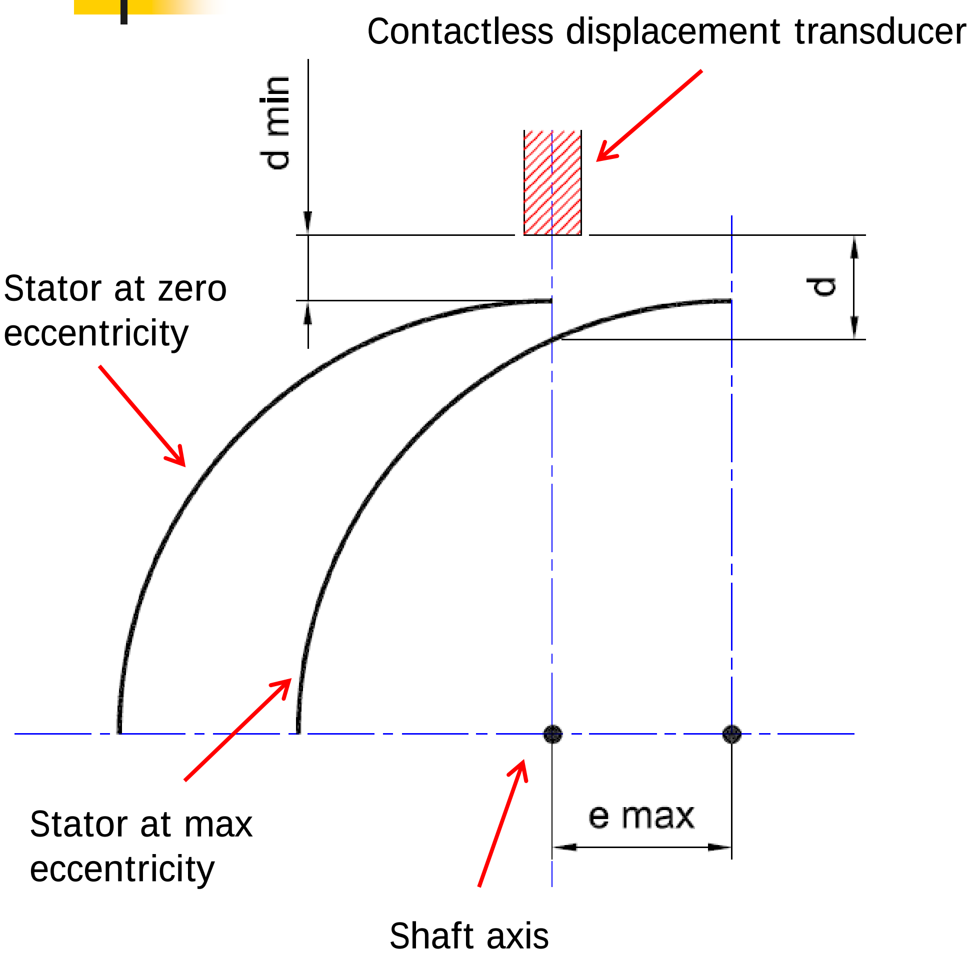


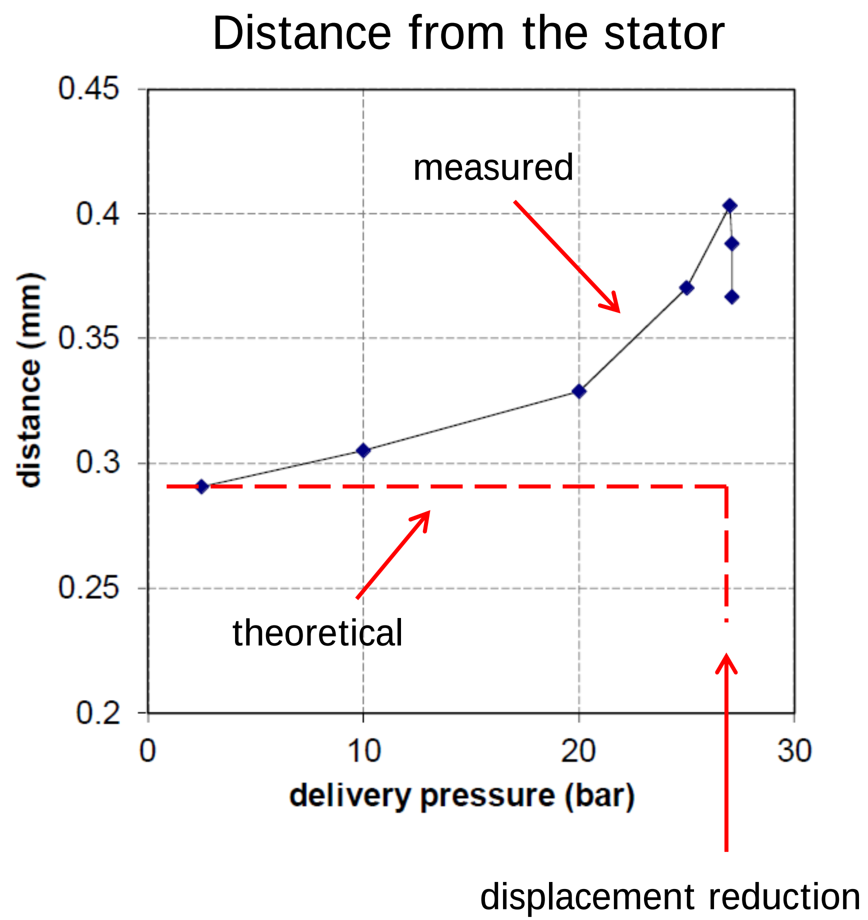
The trend is reasonable (increment with the speed)

but:

- **values >= 1 (!)**
- **At equal speed, higher at high pressure**

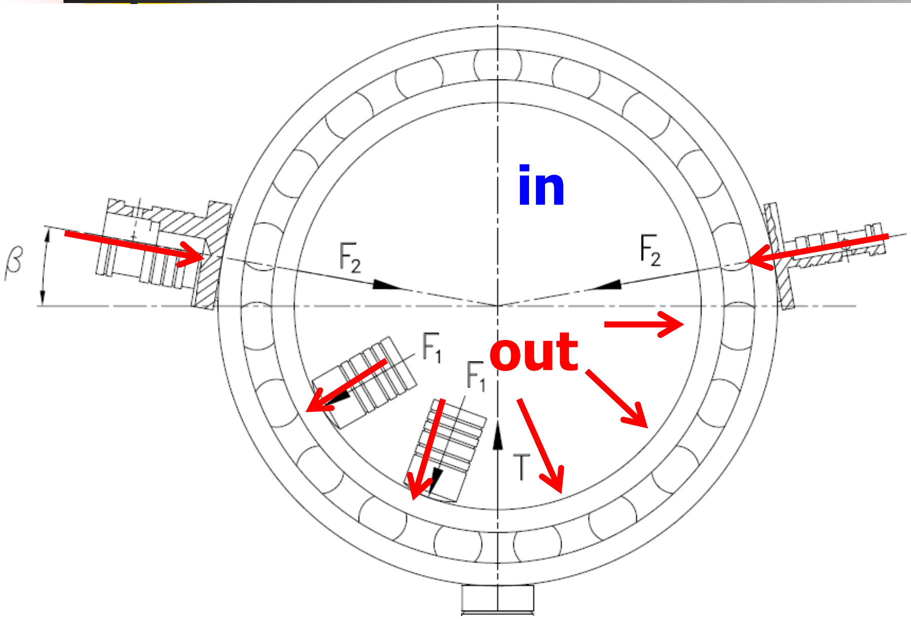
Output of displacement transducer



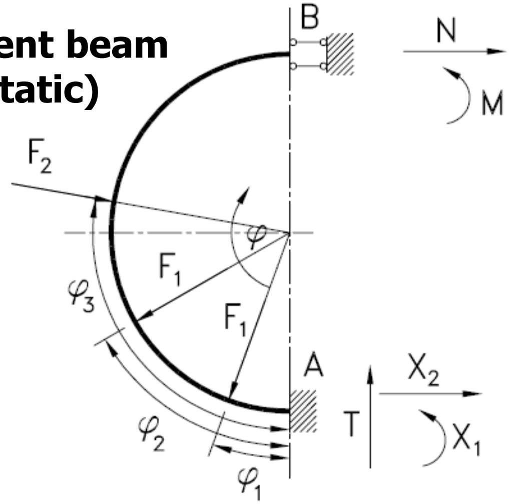


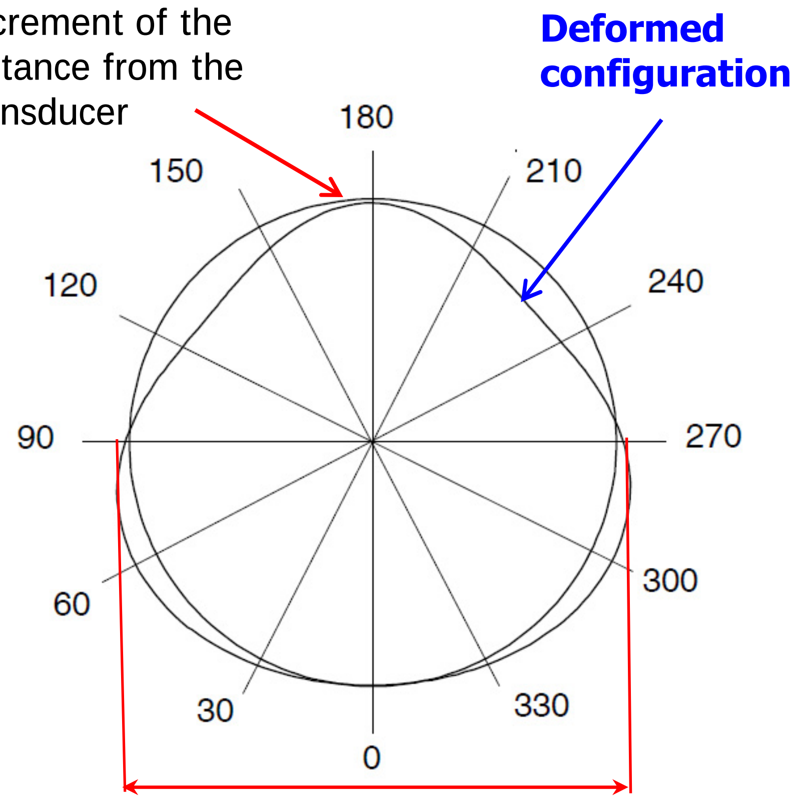
The sensor measured an increment of the distance, but it would have implied an increment of the eccentricity (impossible)

Deformation of the stator



Equivalent beam (hyperstatic)





Increment of the pistons' stroke
-> increment of the pump displacement

→ **The stroke of the piston must be corrected as function of the delivery pressure**

Conclusions

- Nothing is rigid and everything is flexible

  ... even in low pressure machines !

- The “common” best practices for designing the pumps not “always” are the best practices

For in-depth analysis, see also:

- RUNDO M., ALTARE G., CASOLI P. "*Simulation of the Filling Capability in Vane Pumps*", Energies 12(2), 2019.
- ALTARE G., RUNDO M. "*Advances in simulation of gerotor pumps: An integrated approach* ", Proc. IMechE Part C: 231(7), 2017.
- RUNDO M., PAVANETTO M.A. "*Comprehensive Simulation Model of a High Pressure Variable Displacement Vane Pump for Industrial Applications*", ASME IDETC/CIE 2018, Quebec City.
- CARETTO R., MANCÒ S., NERVEGNA N. RUNDO M. “*Modelling, Simulation and Experimental Studies on a Variable Displacement Radial Piston Pump Prototype for Automotive Applications*” ASME FPST 1996, Atlanta.

Thank you for your kind attention