Experimental Investigation of a new Hydrostatic Bearing

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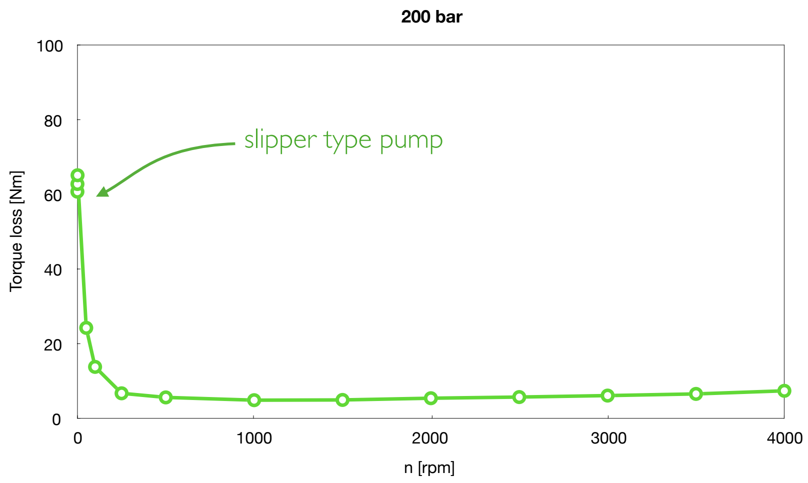
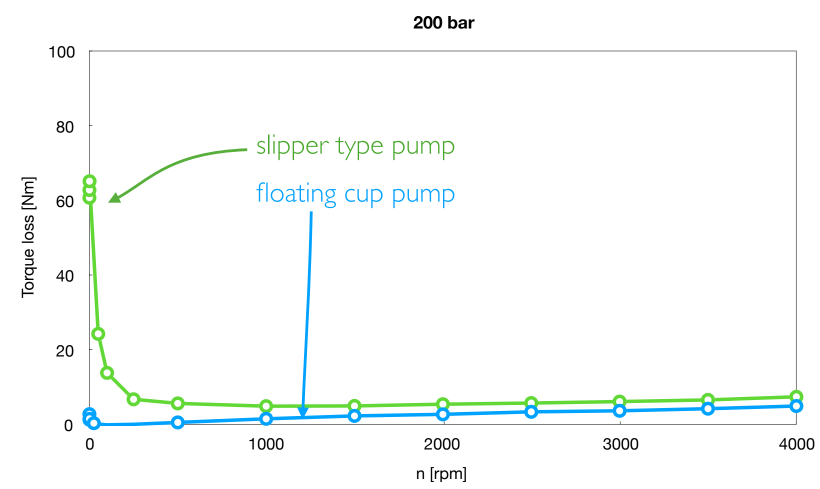
The art of designing hydrostatic pumps and motors is to create narrow gaps in moving sealing areas, without creating high friction losses. It is about tribology: the science and engineering of interacting surfaces in relative motion. One of the most important concepts in tribology is the so called Stribeck curve.

measured torque loss (friction)

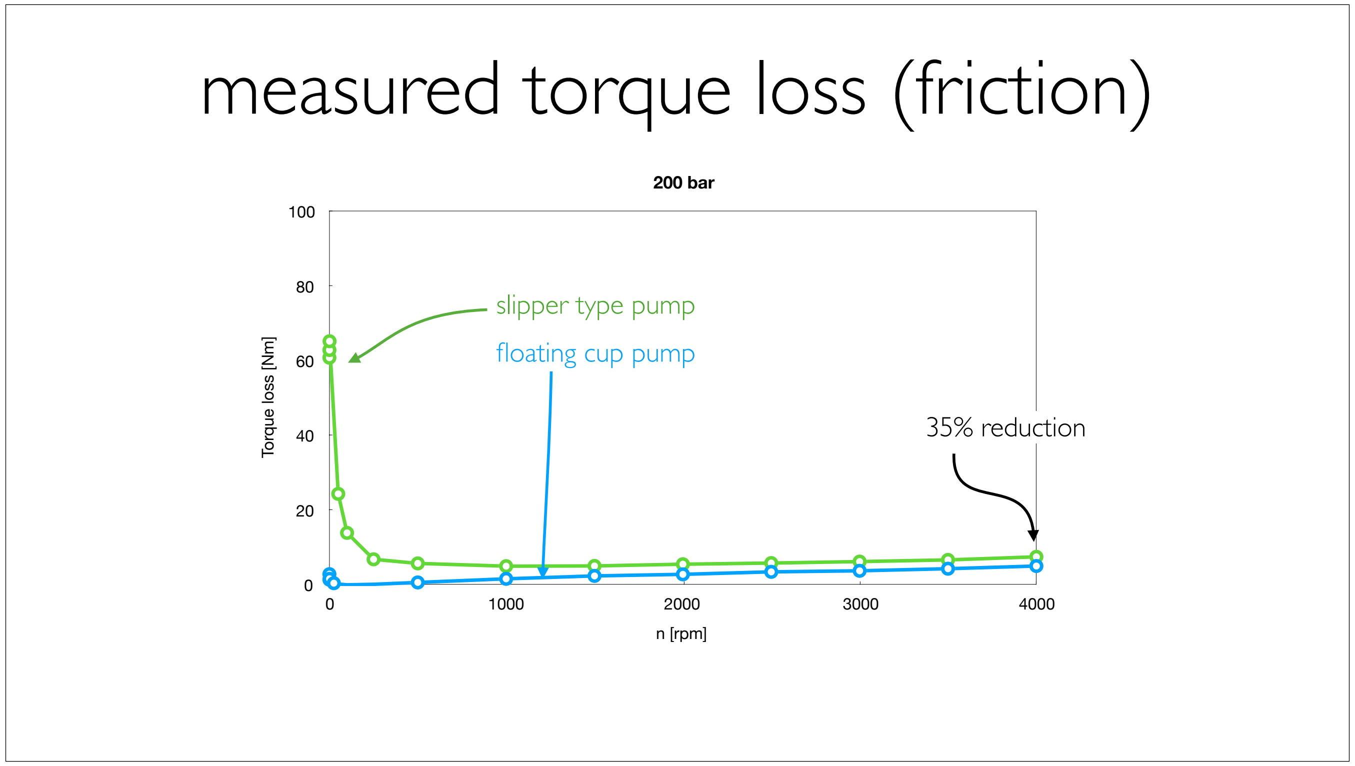


Here you see such a Stribeck curve. This is a measurement in our lab of a conventional slipper type pump. The curve shows the strong increase of friction when the rotational speed of the pump is reduced.

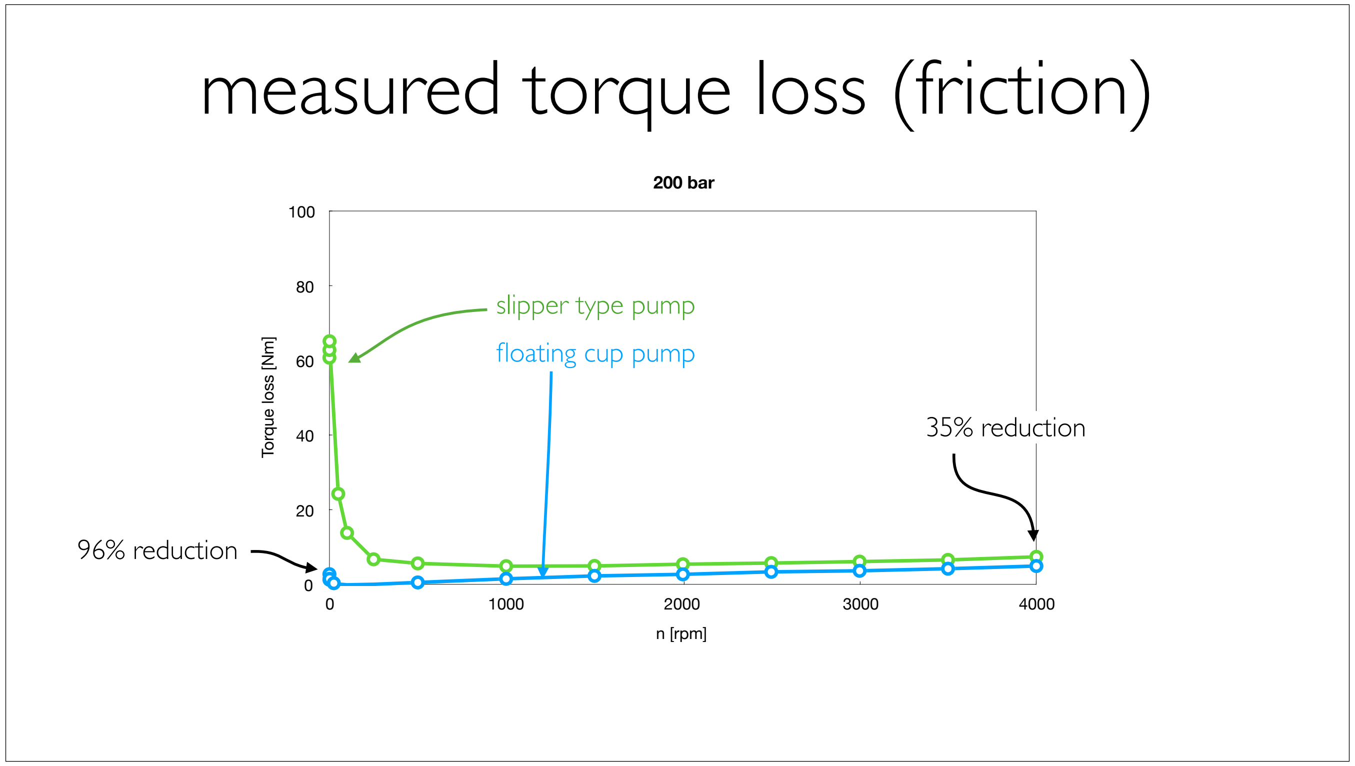
measured torque loss (friction)



This is the same measurement, but now performed on one of our floating cup pumps. Both pumps have about the same displacement and are measured at the same conditions.

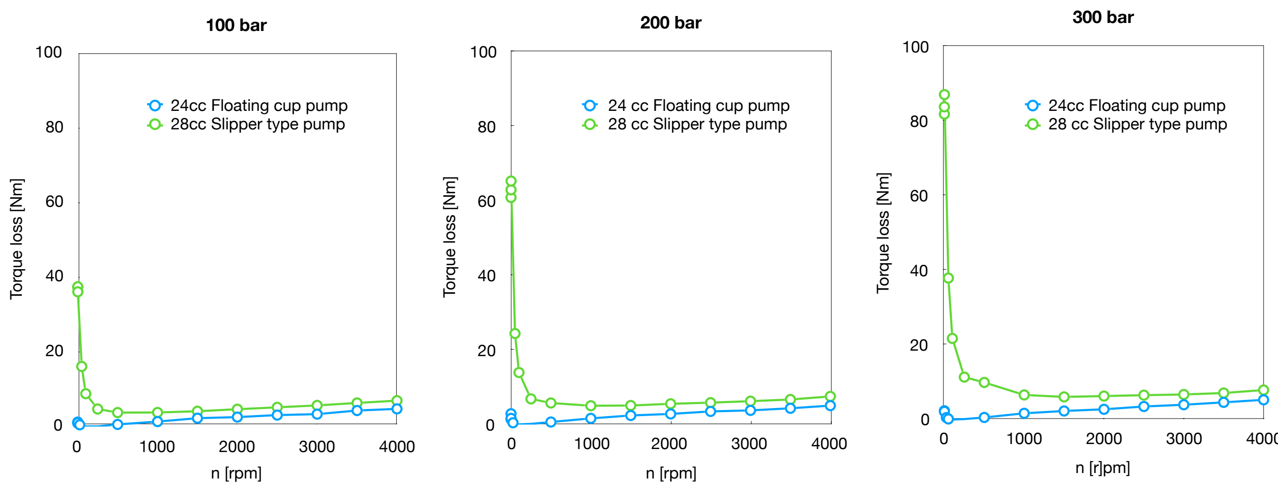


Yet, the floating cup pump reduces the friction at high speeds with about 35%.

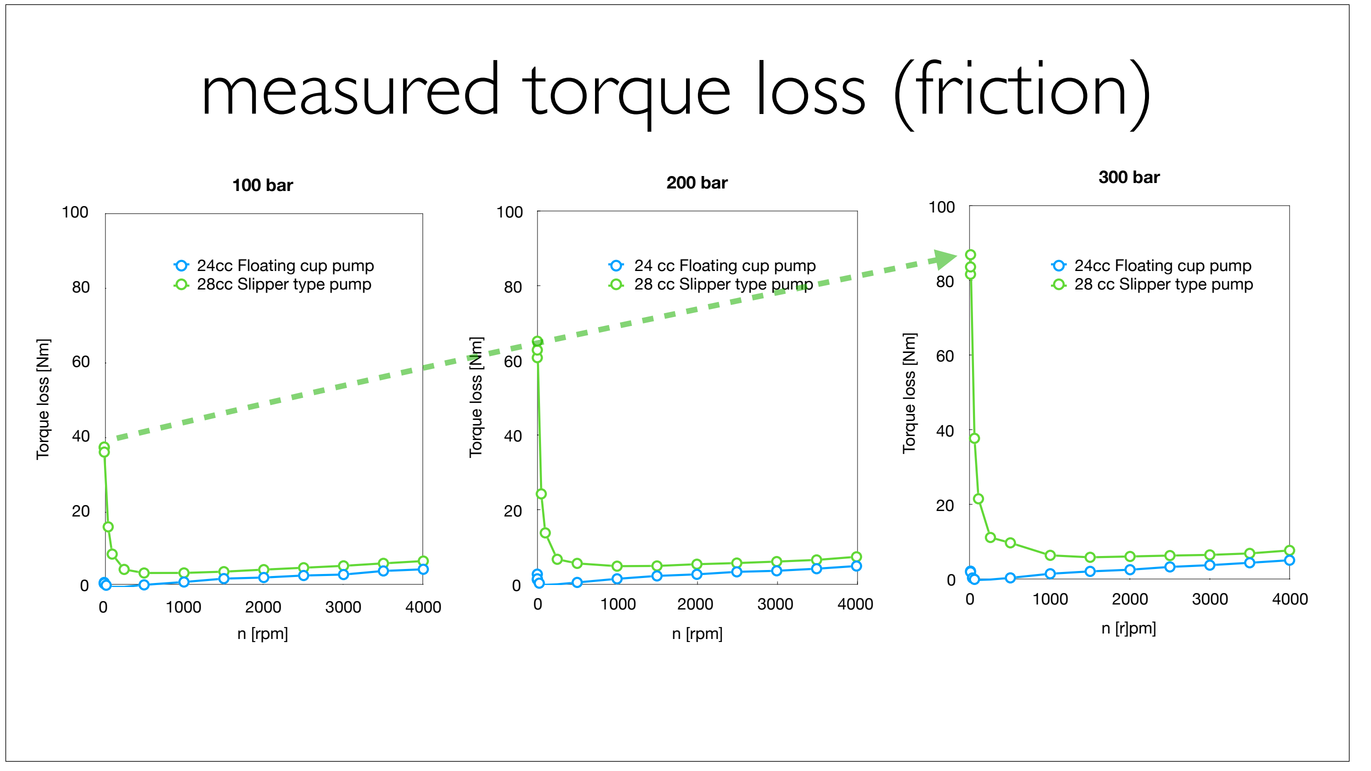


But the most remarkable difference is the disappearance of the high friction at low speeds. The mixed lubrication and boundary lubrication have almost completely disappeared. Now, these are measurements performed at 200 bar.»

measured torque loss (friction)

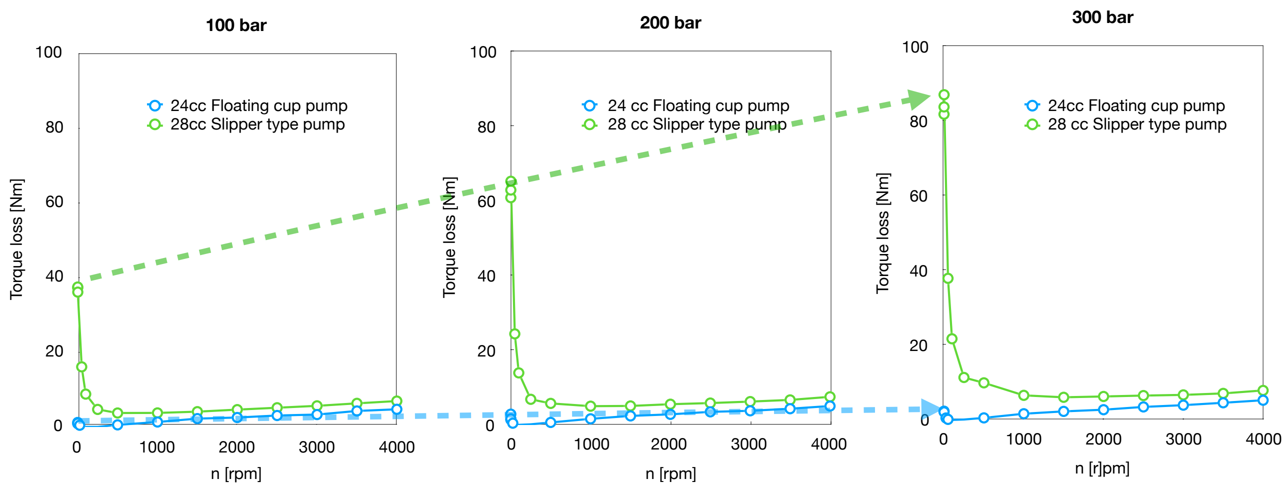


Similar results can be seen at 100 and 300 bar pump pressure.



But, where the friction strongly increases for the slipper type unit, …

measured torque loss (friction)

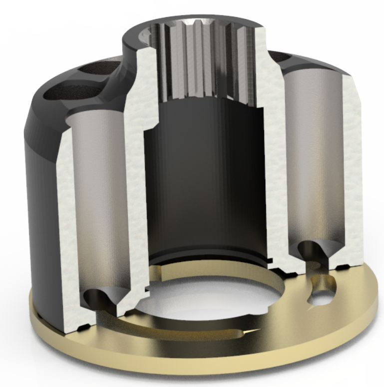


…the friction for the floating cup pump stays almost constant at a very low level.
Part of the effect is due to the floating cup principle itself, which eliminates friction forces between the pistons and the cylinders. But another important reason can be found in the new design of the sealing lands of the barrel. That is the topic of this presentation.

a new hydrostatic bearing

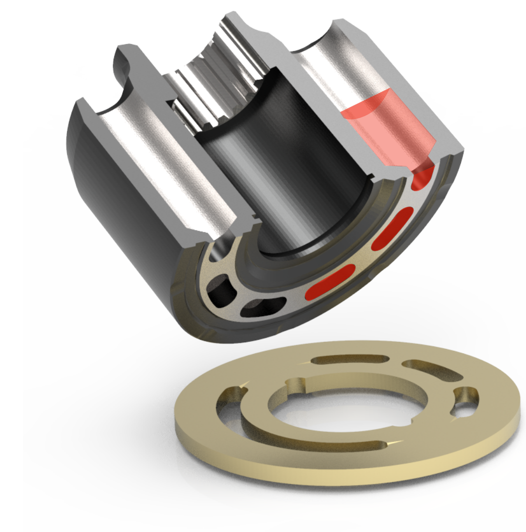
It is about a new hydrostatic bearing we developed for hydrostatic machines. A bearing which also functions when the operating speed is low or even close to zero. But also a bearing which stabilises the barrel position at high operating speeds, thereby avoiding the risk of barrel tipping and malfunction of the pump.

conventional design

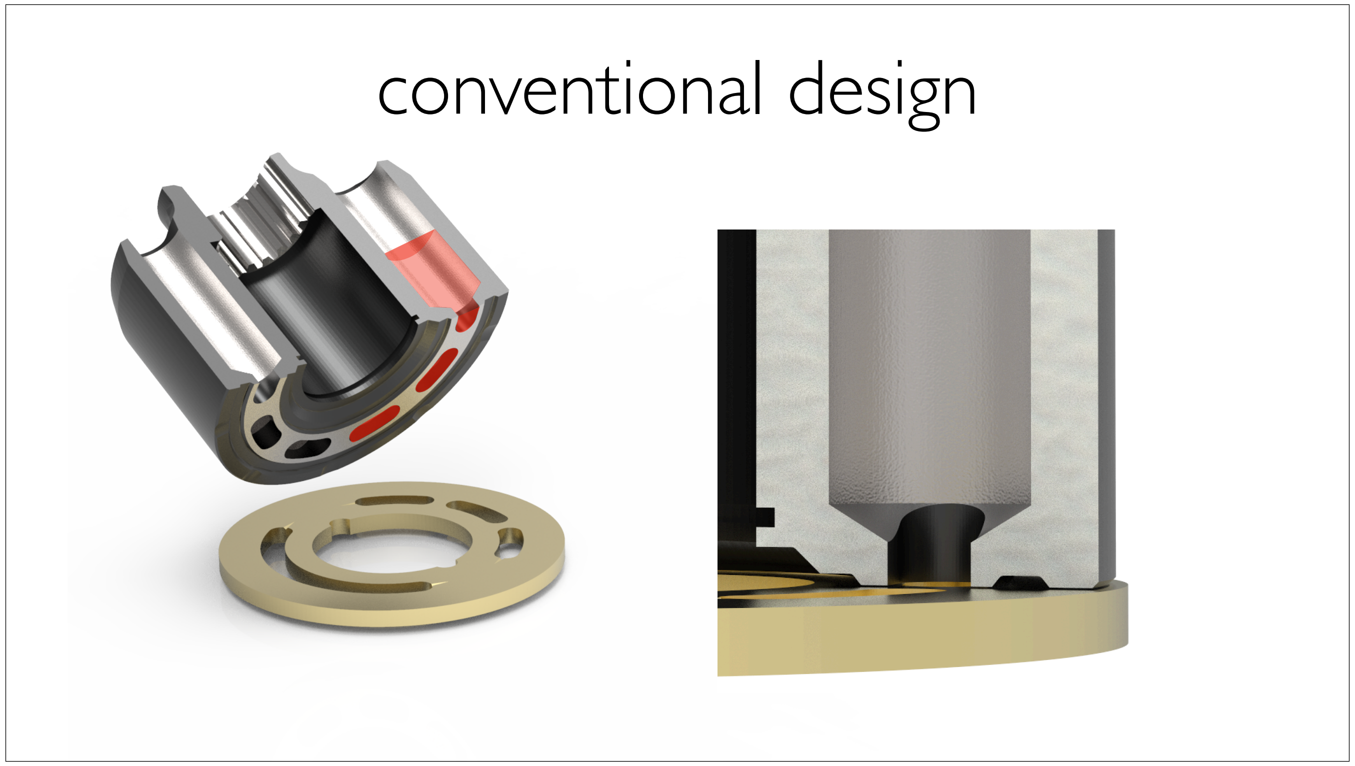


Let’s first look at the conventional design. Here we see a cross section of the barrel of a slipper type pump. It is resting on a port plate.

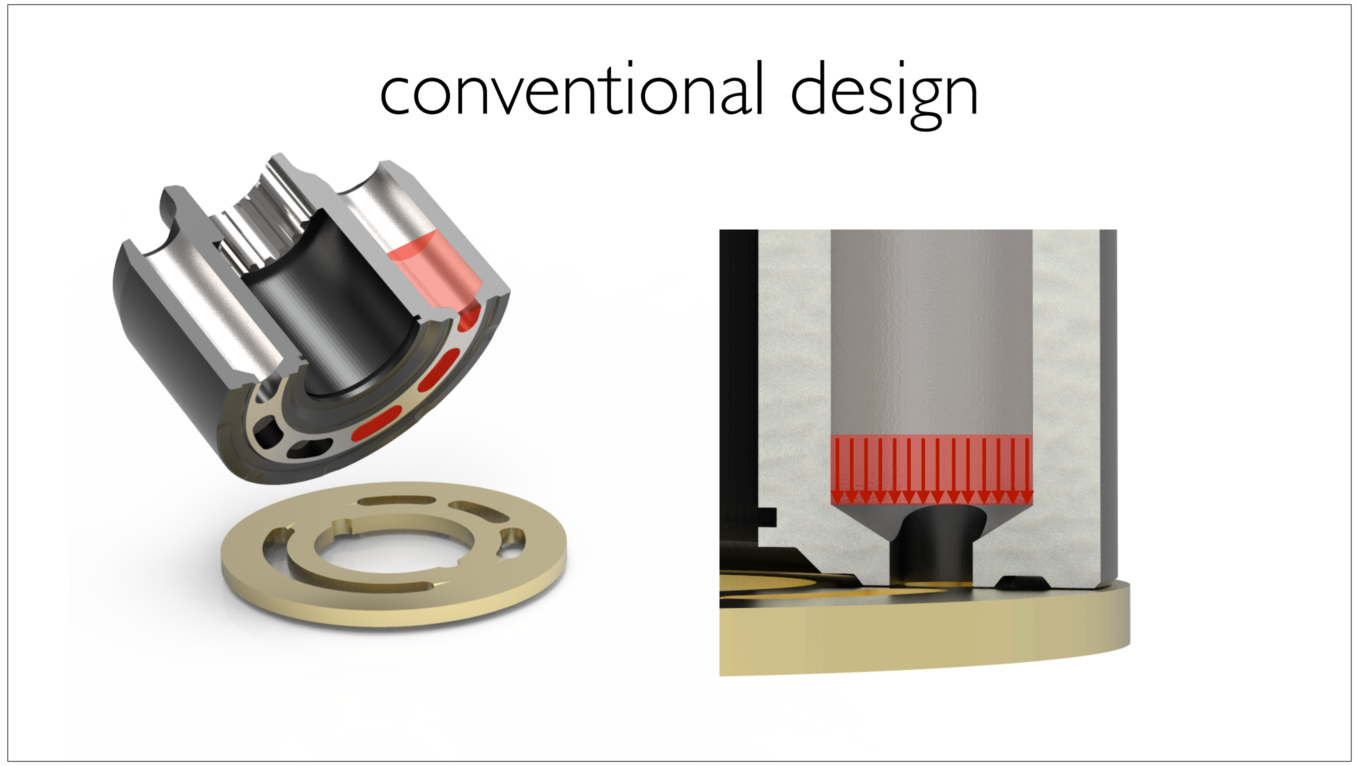
conventional design



The contact between the two parts is realised in the sealing lands. These are first of all needed to avoid high leakage from the barrel ports to the pump case.

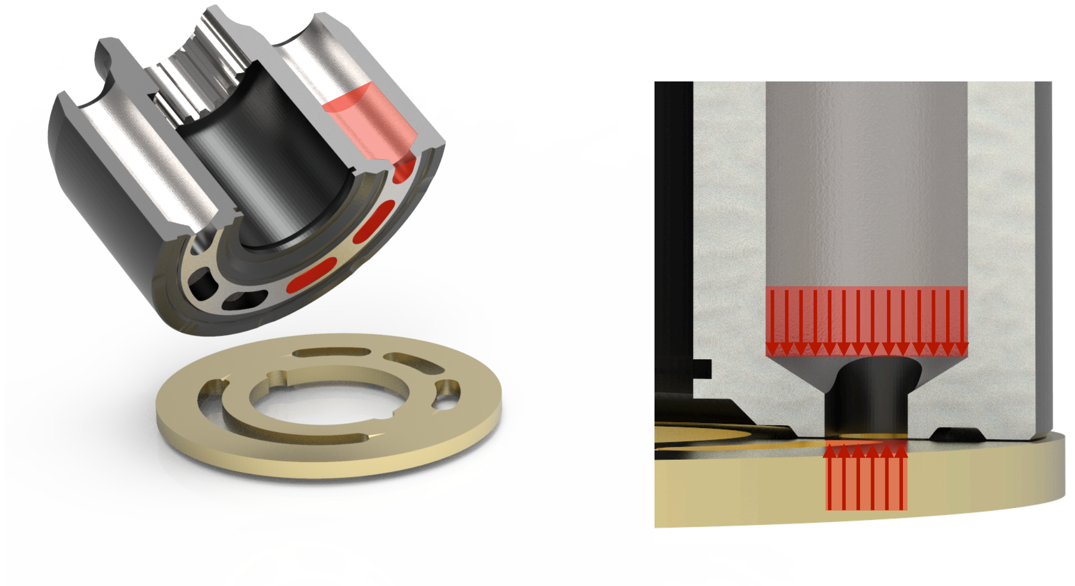


But, they are also needed for creating a pressure field to balance the barrel loads. Aside from centrifugal and friction forces, the most dominant force…

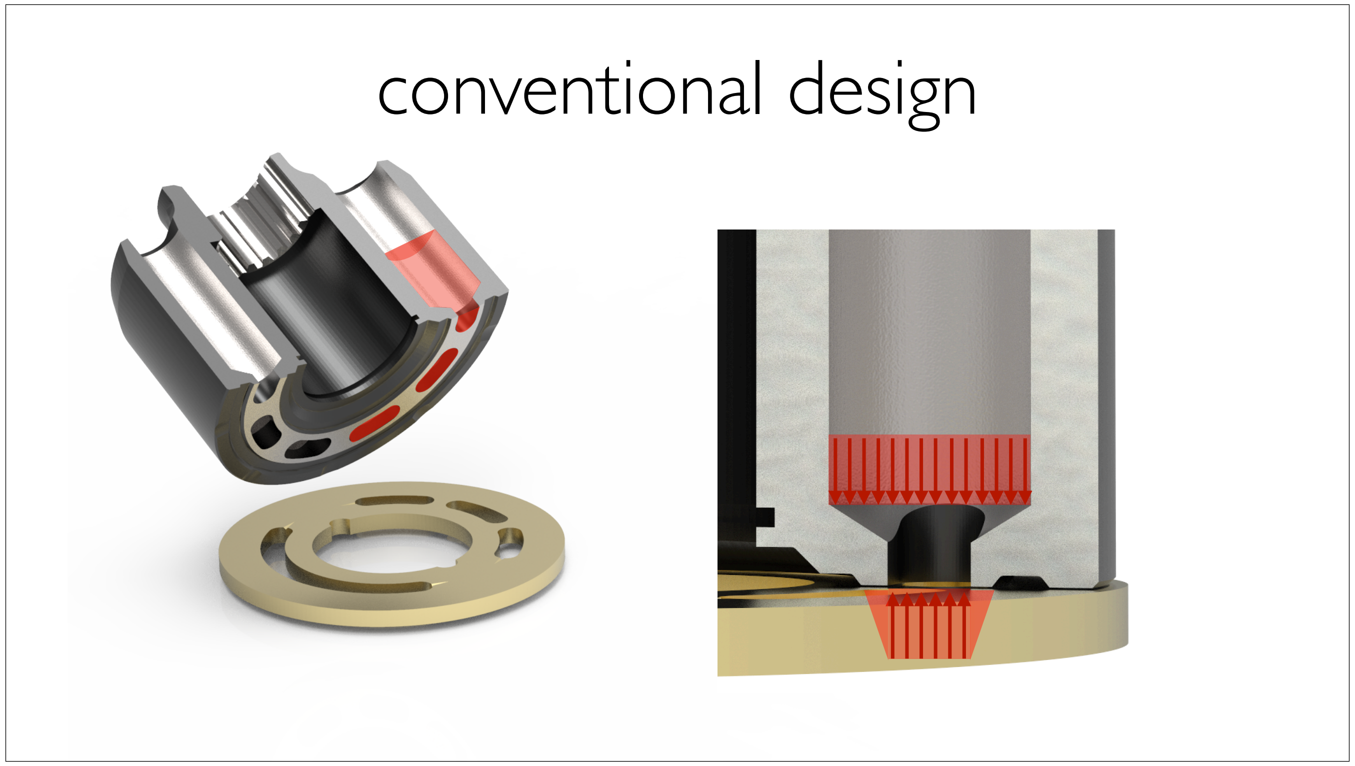


… is created by the pump pressure in the cylinder. The axial force of this pressure field needs to be compensated by another hydrostatic force, otherwise it would be impossible to rotate the barrel

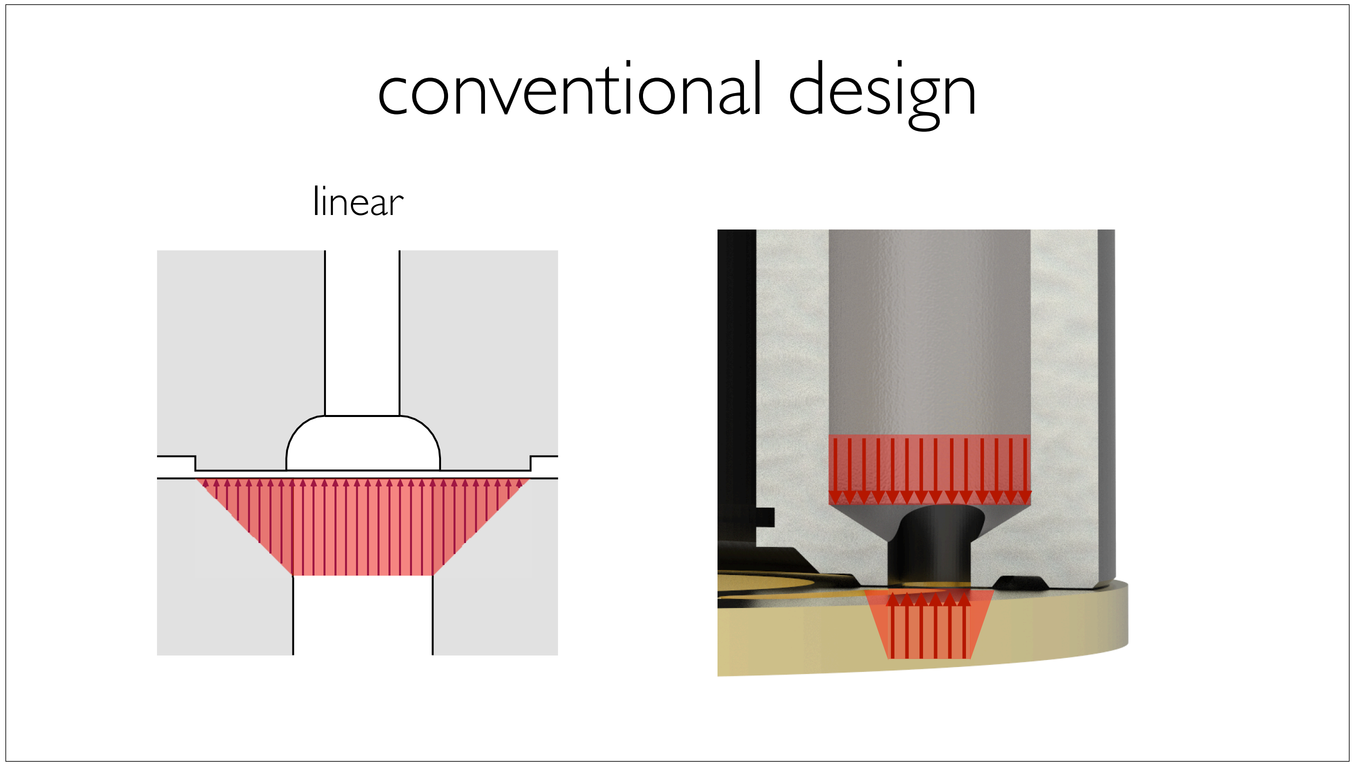
conventional design



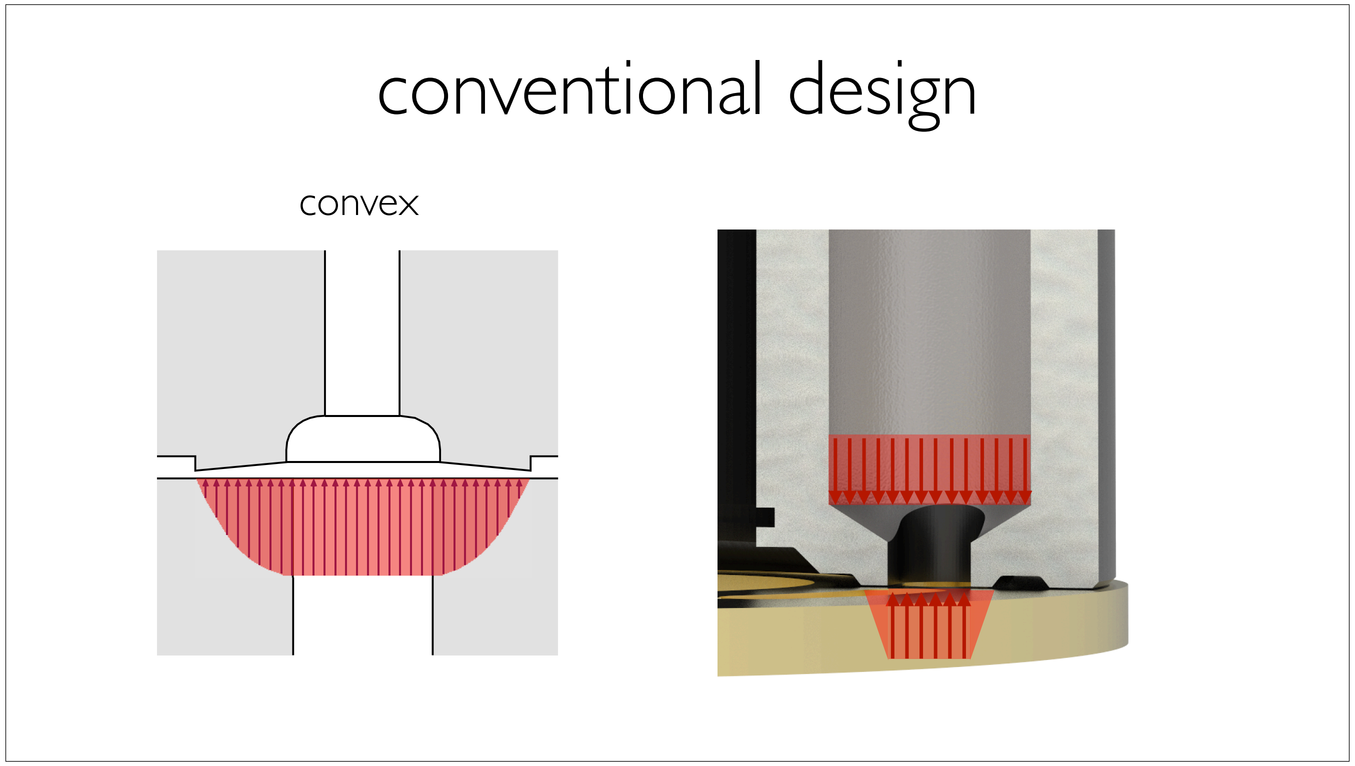
This counteracting hydrostatic force is coming for a part from the barrel ports



But the sealing lands also create a substantial hydrostatic force. They might be narrow, but they are quite long and have a crucial effect on the balancing of all the barrel forces.

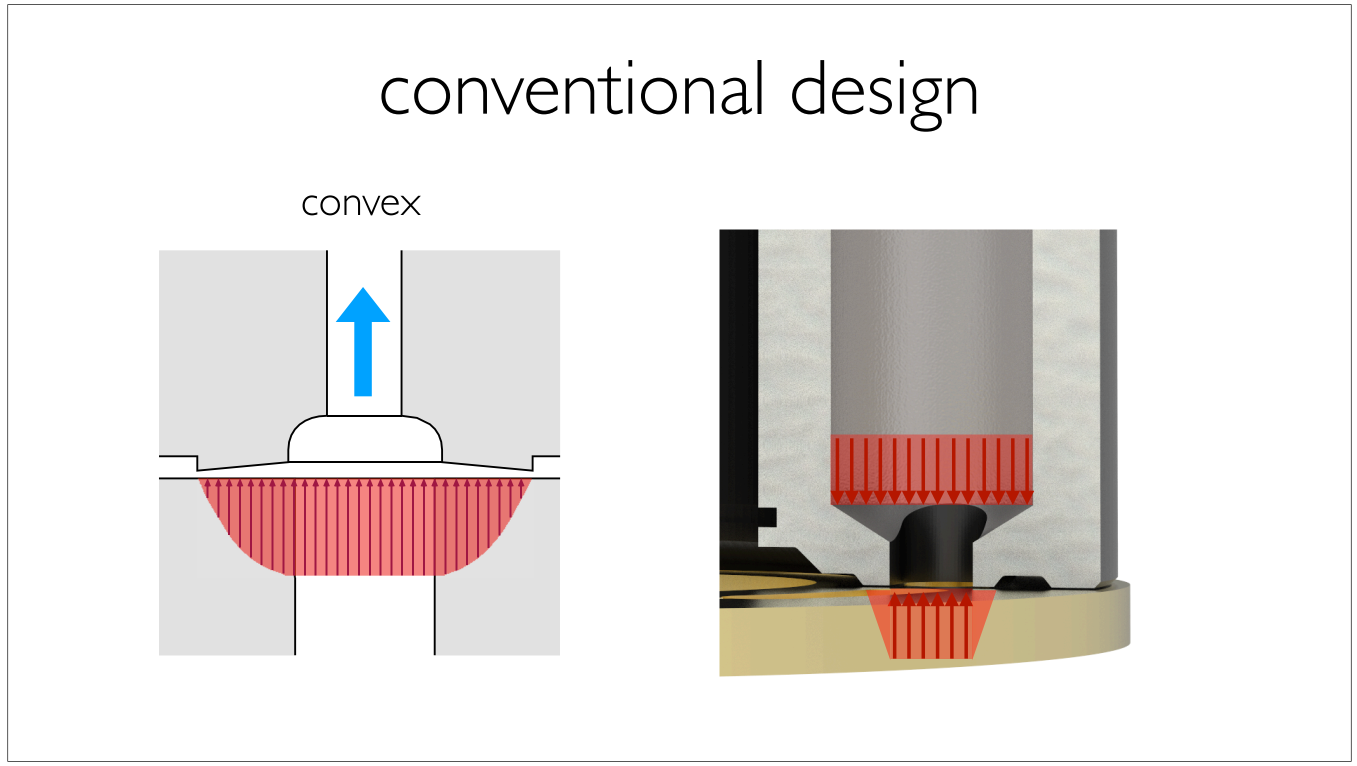


The problem is that we don’t know how the pressure drop in the sealing land looks like. It can be linear when the gap height is constant and the viscosity of the oil doesn’t change. But in reality the oil heats up during the passage from the barrel port to the pump case, and as a consequence the oil viscosity is far from constant. Furthermore, the pressure drops which also effects the viscosity, and hence the pressure profile.



And then we have elastic deformation of the barrel, including the barrel sealing lands, as well as thermal deformation. As a result the sealing land areas of the barrel and the port plate won't be parallel. In addition there are production tolerances and wear which also influence the shape of the gap profile. As a result the pressure field in the gap can become convex, as is shown in this drawing.

» This could create such a large additional force that the barrel will be lifted or tilted, and the pump would stop working in a proper way.



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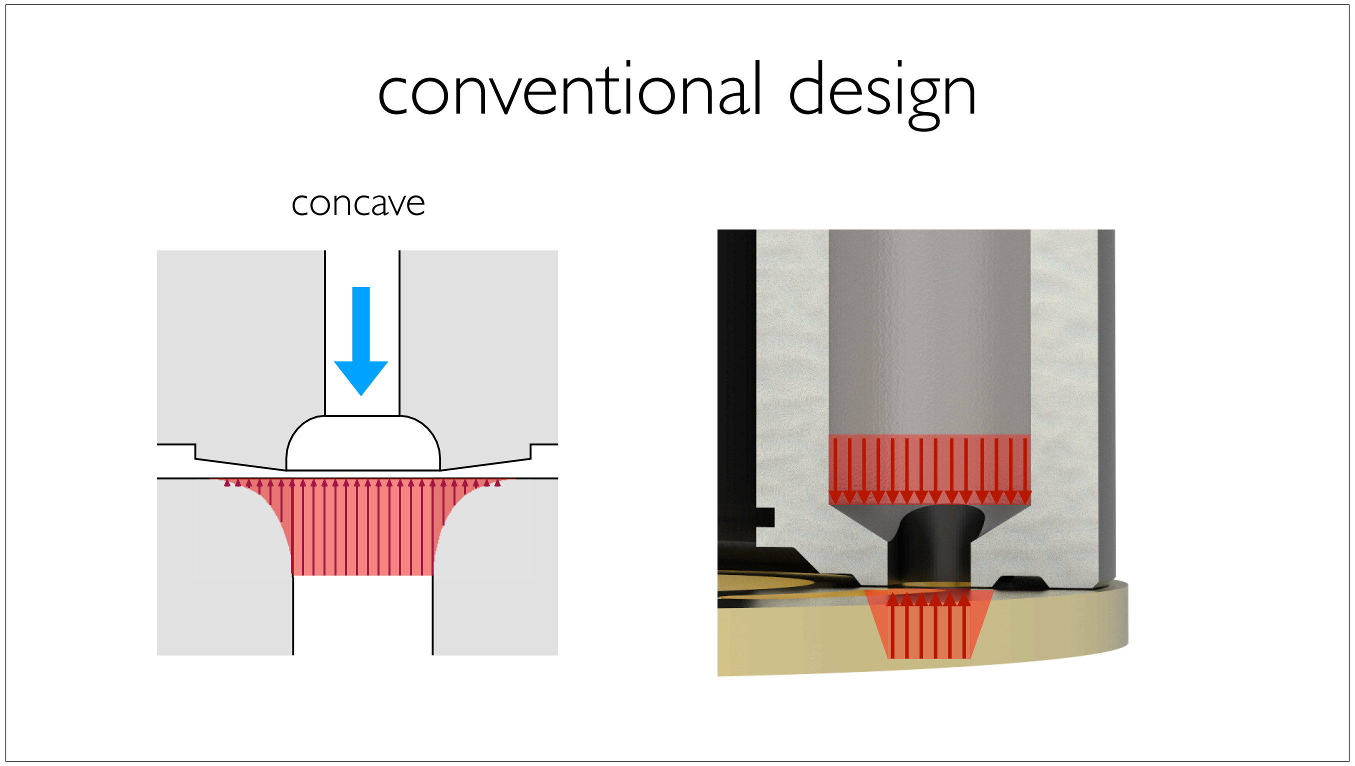
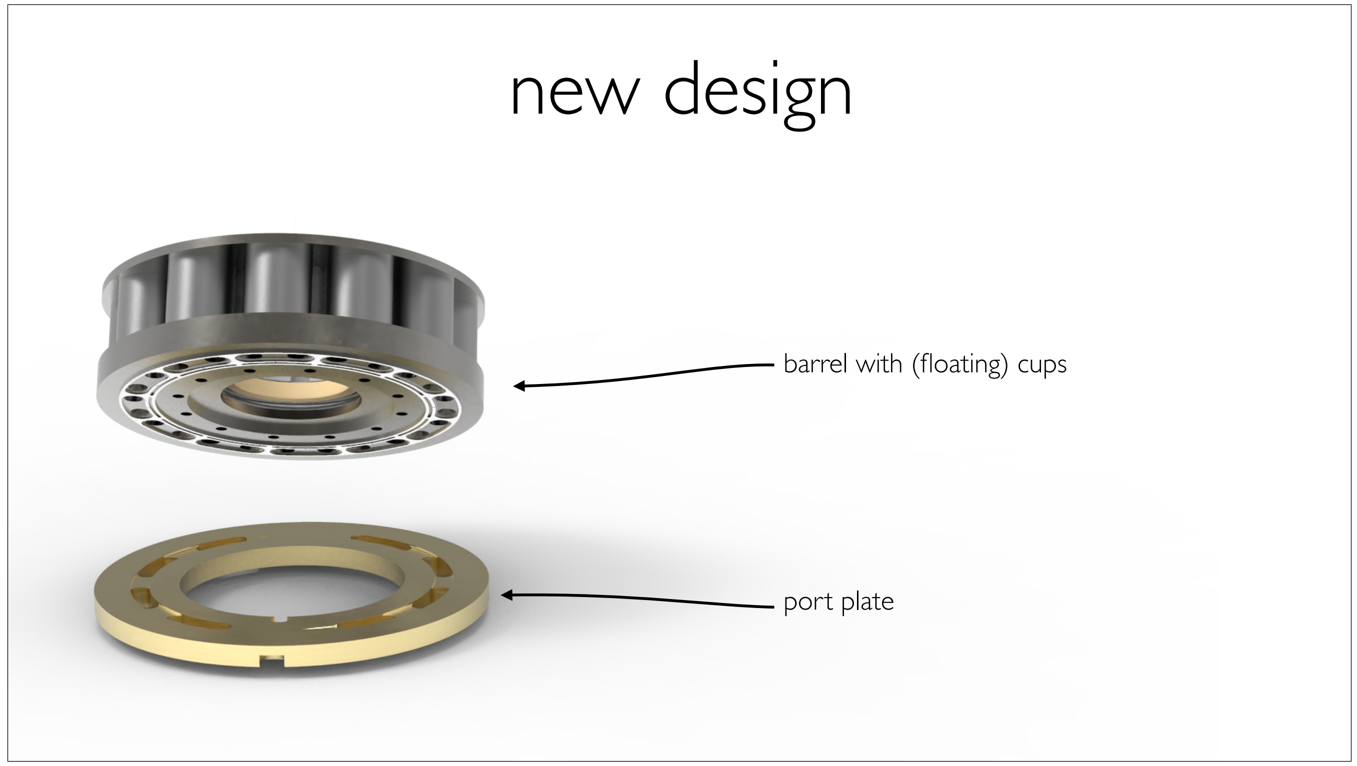


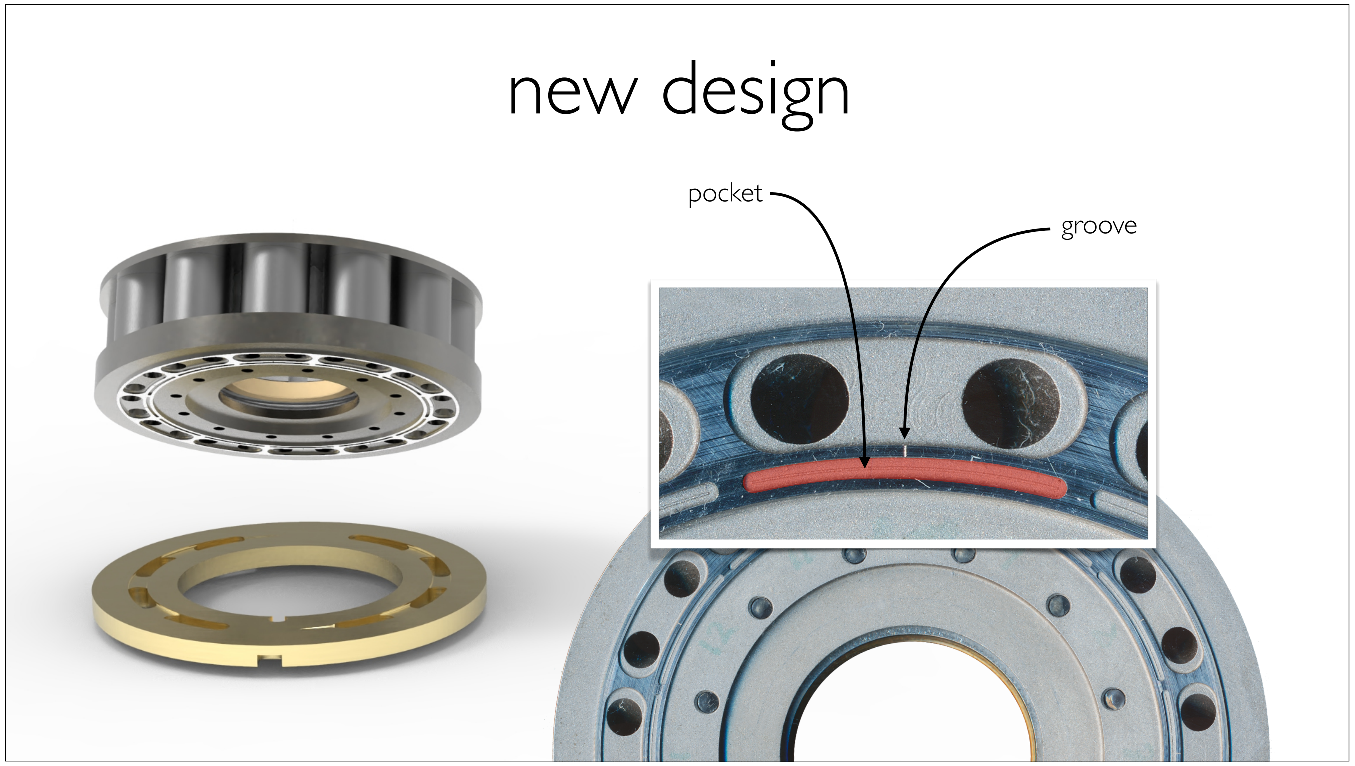
But the pressure profile could also become concave, in which case the barrel will be pushed with a large force to the port plate. At high operating speeds, the hydrodynamic effects will again lift the barrel and create an oil film, but at low rotational speeds, these effects will disappear, and the friction will go up.



But, there is a solution, which we applied in or floating cup machines. Here you see
» a quite ordinary port plate
» and the barrel of a floating cup pump
The shiny surface at the bottom of the barrel is the new sealing land or bearing that we designed and applied in this pump

Let’s have a closer look at this design. Here you see a picture of one of the barrel ports,…

… being surrounded by the sealing lands. On the outer diameter we have one sealing land, like in the conventional design, but the inner sealing land we have split in two areas…



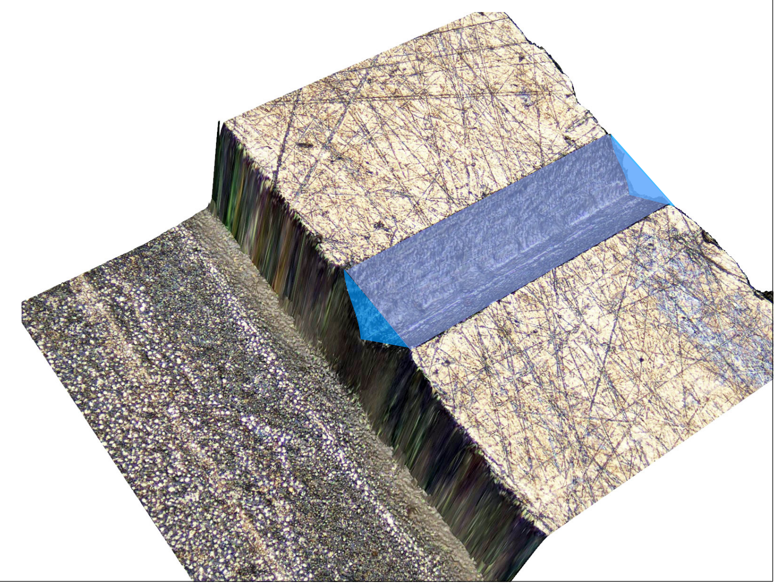
…being separated by a recessed area which we call a pocket. The most important design feature is
» a small groove, which connects the barrel port to the pocket. This groove is needed to create a pressure in the pocket which is dependent on the gap height. We know that the groove needs to be small. In this design somewhere around 150 micron in width and 70 micron in depth.

what size should the grooves be?

We only don’t exactly know how small the groove should be? To investigate this we decided to perform an experimental research project.

what are the effects of the groove?

- on the case drain?
- on the torque loss (friction)?
- on the overall efficiency?
- on the average losses



We wanted to learn about the effects of the groove dimensions on the volumetric losses, the torque losses, and the overall efficiency of the pump. Not just in one operating point, but in many operating points. In the end we determined the effect of the groove width and depth on the average power loss of the pump.

experimental procedure

Before I show you the results, I need to explain the experimental procedure of this project.

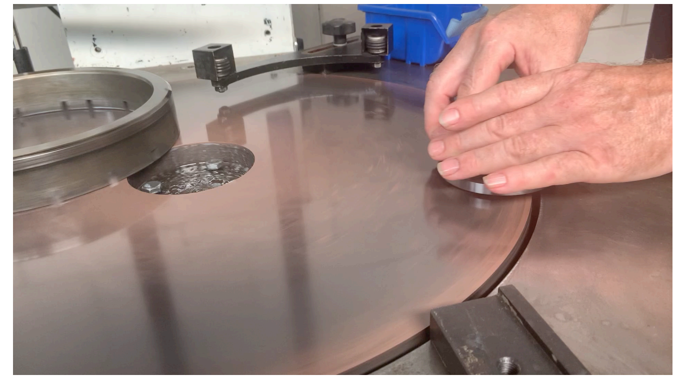
procedure

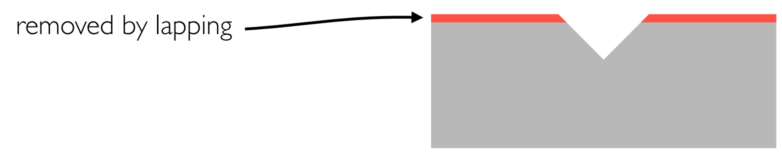
lapping of the sealing lands of the barrels

The first step is lapping of the sealing lands of the barrel.

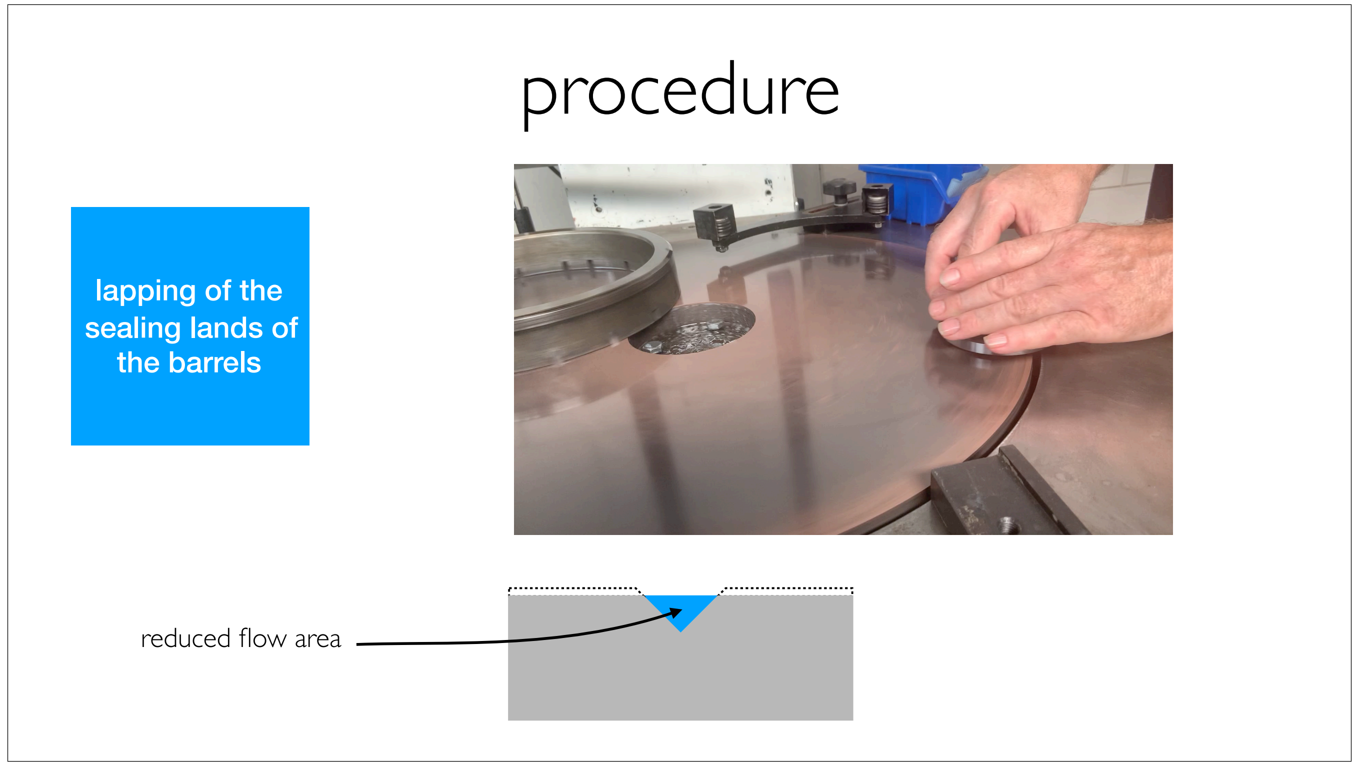
procedure

lapping of the sealing lands of the barrels



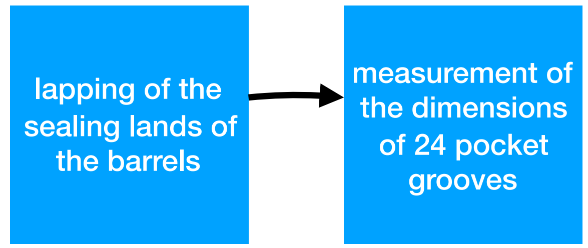


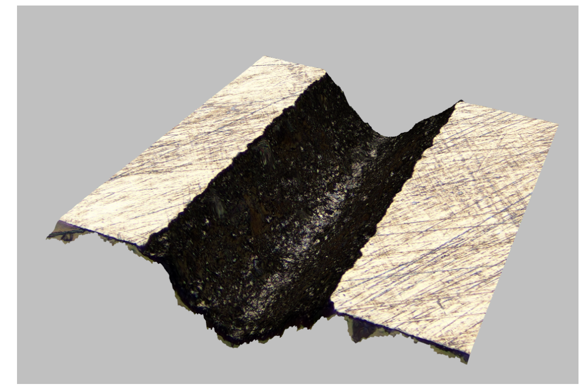
By lapping, we can control the width and depth of the groove, and therefore the flow area and the flow resistance of the groove.



We start width large size, and reduce the groove size step by step by means of lapping. Each lapping step takes away about 5 to 10 micron of the surface.

procedure

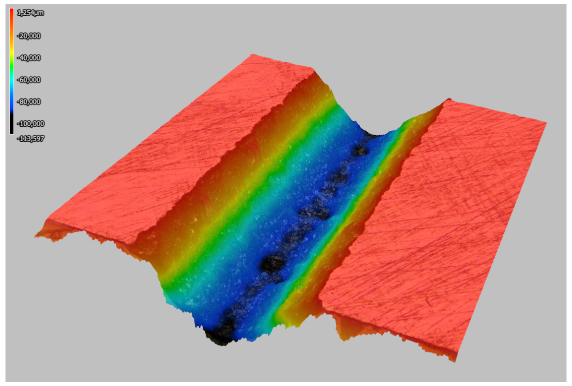




After each lapping procedure, we have measured the dimensions of all grooves. The are 12 grooves in one barrel, but the floating cup pump has two barrels. Therefore we have to measure 24 grooves.

procedure

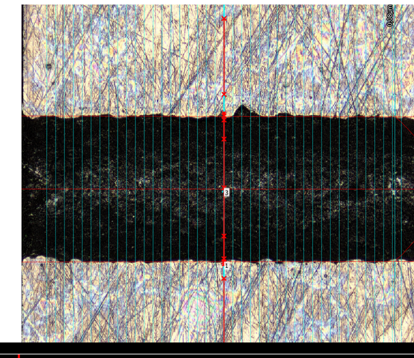
lapping of the sealing lands of the barrels → measurement of the dimensions of 24 pocket grooves

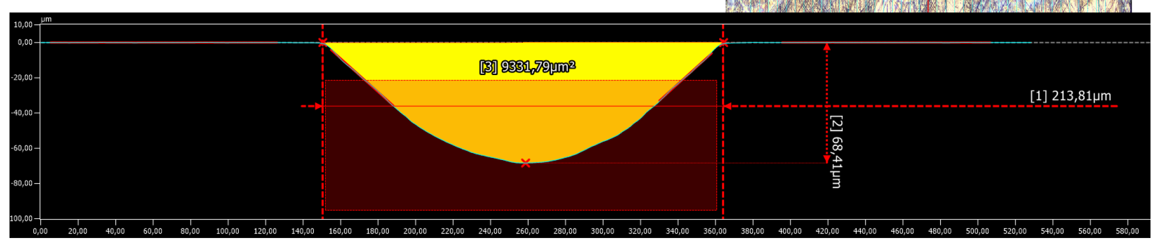


Modern digital microscopes nowadays allow precise 3D- measurements of design details like the grooves.

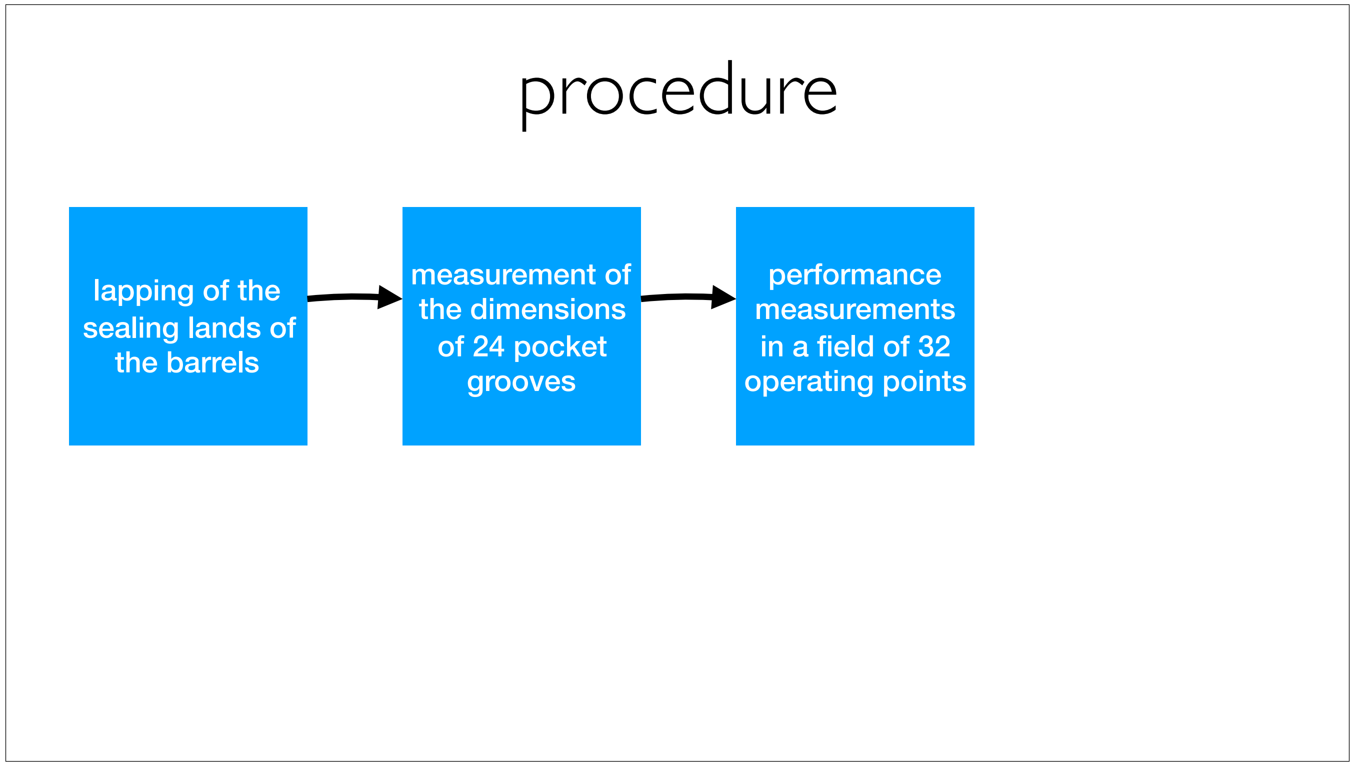
procedure

lapping of the sealing lands of the barrels → measurement of the dimensions of 24 pocket grooves

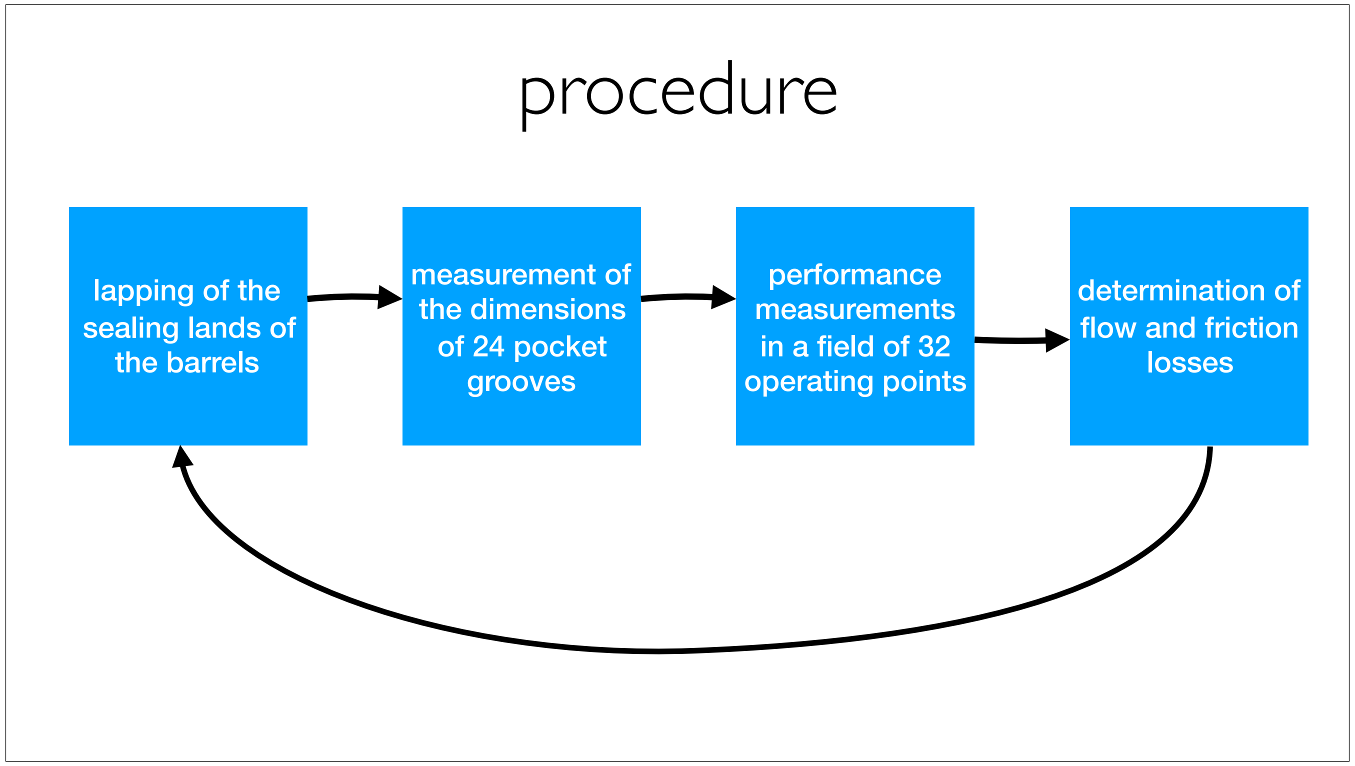




The software of these microscopes also allows to determine the average width, height and flow area of each groove.

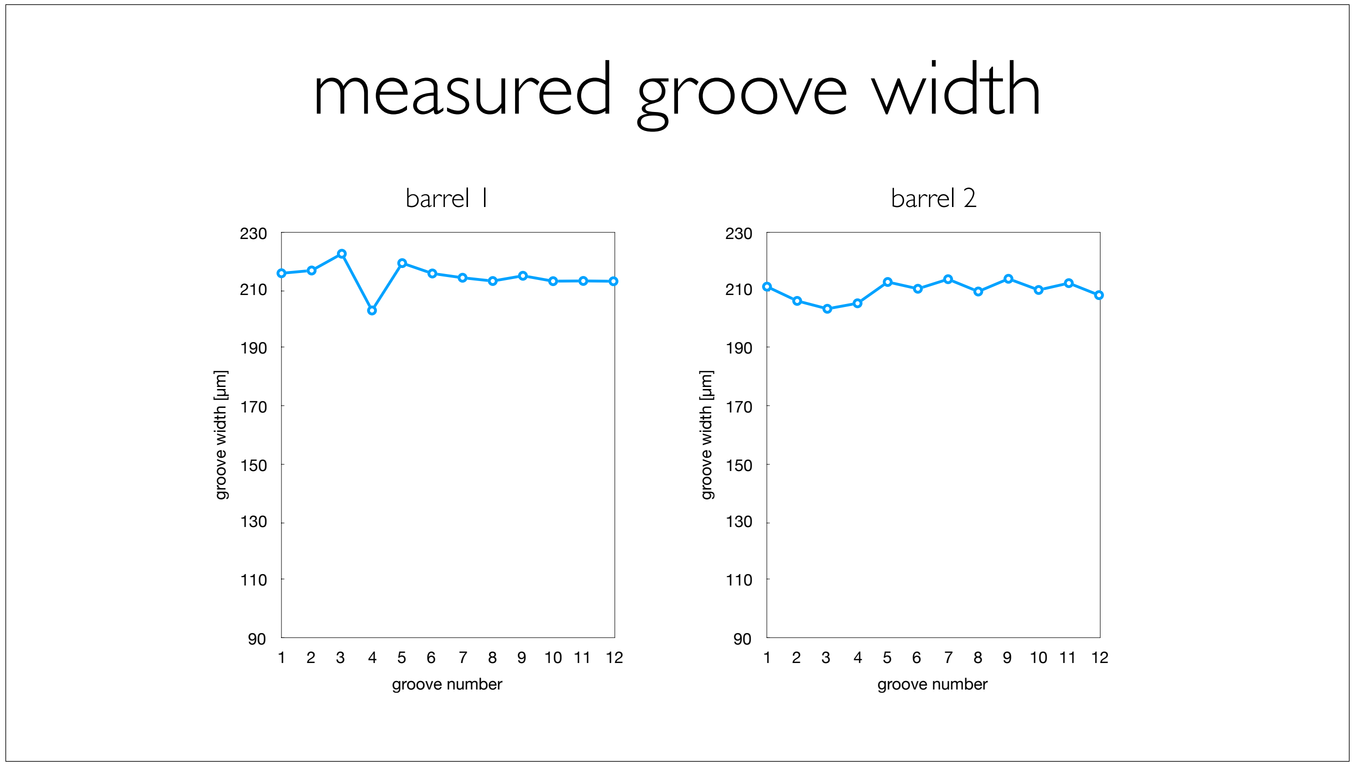


The nest step is to assemble the pump and perform measurements in order to determine the volumetric and hydro-mechanical losses in various operating points.

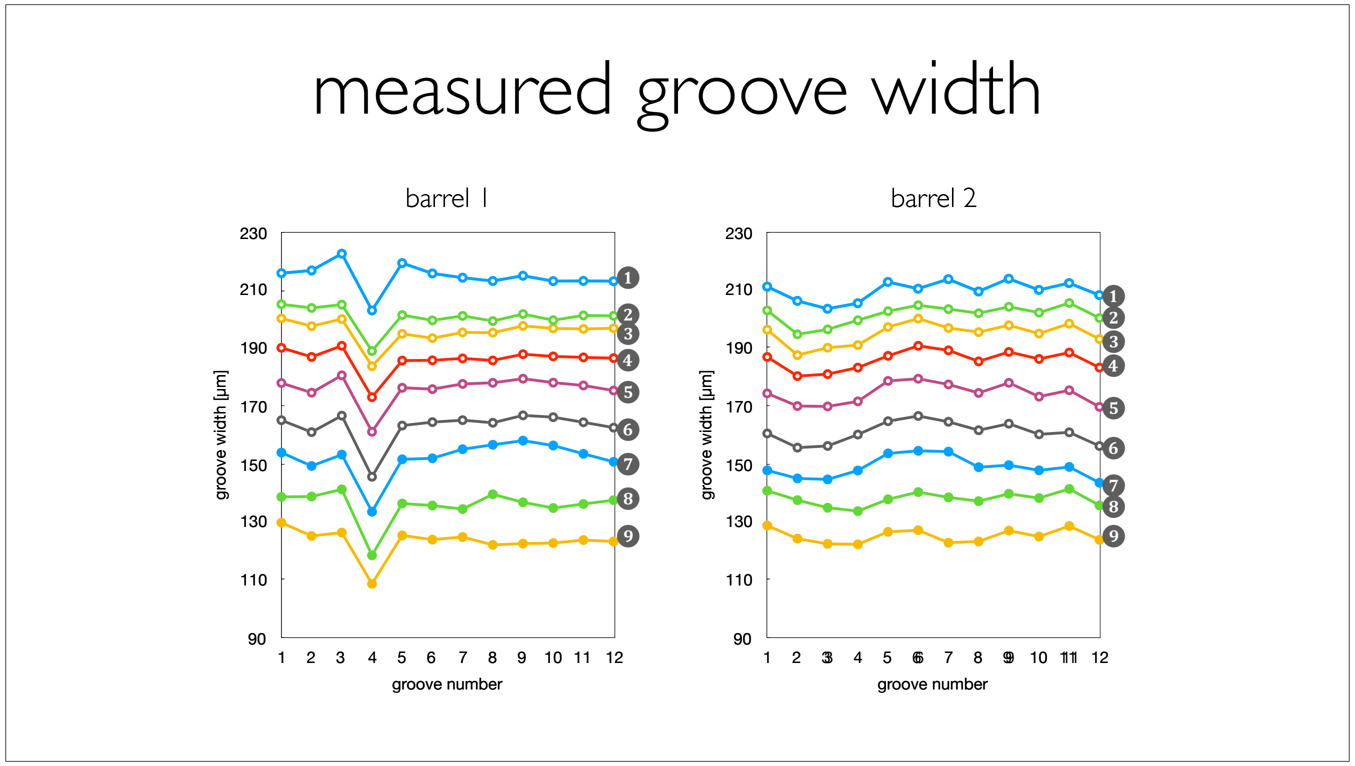


Finally we analyse these data and start with another lapping procedure.

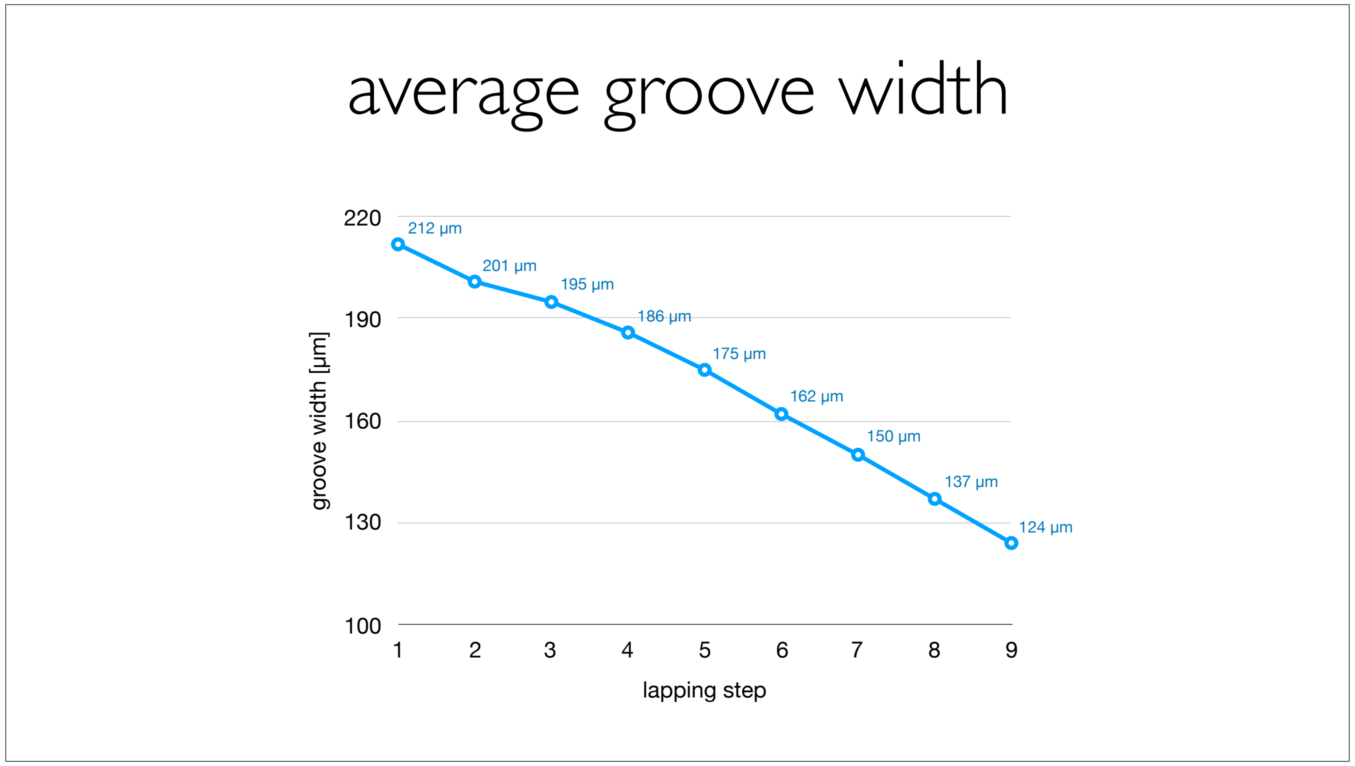
Results



Here you see the measured width of 24 grooves after the first lapping action. As expected, the grooves don't have the same dimension. Especially the third groove of the first barrel is deviating.

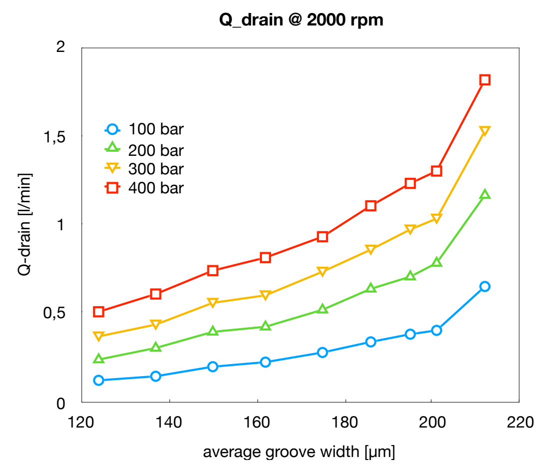


In total we performed 9 rounds of lapping, groove measurements, pump performance measurements and analysis.



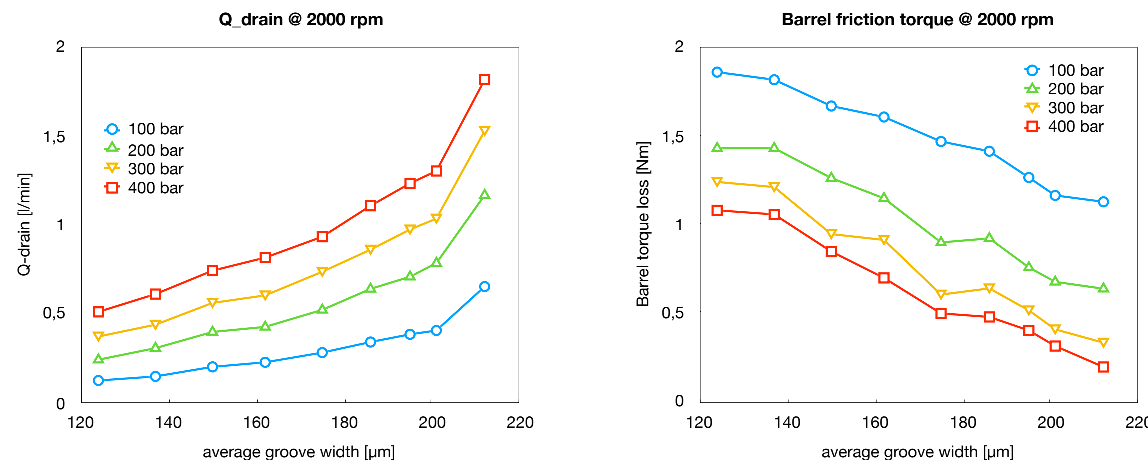
On average, the groove width has been reduced from 212 micron to 124 micron. With every step, not only the width is reduced, but also the depth. In the end the flow area of the grooves has been reduced by a factor of three.
Now, let me show what effects we have measured.

effect on case drain and barrel friction



First of all the effects on the case drain flow. A smaller groove size clearly reduces the pump leakage, especially in the first step.
This is understandable. A smaller groove has a larger flow resistance, which reduces the pressure in the pocket. As a result, the barrel will run closer to the port plate and the leakage is reduced.

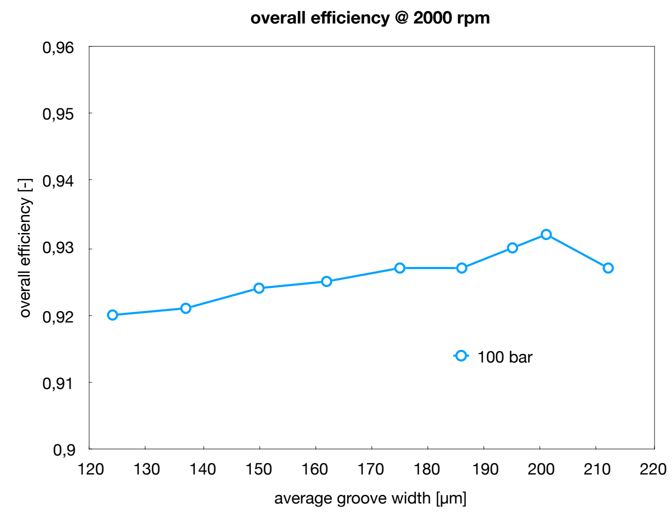
effect on case drain and barrel friction



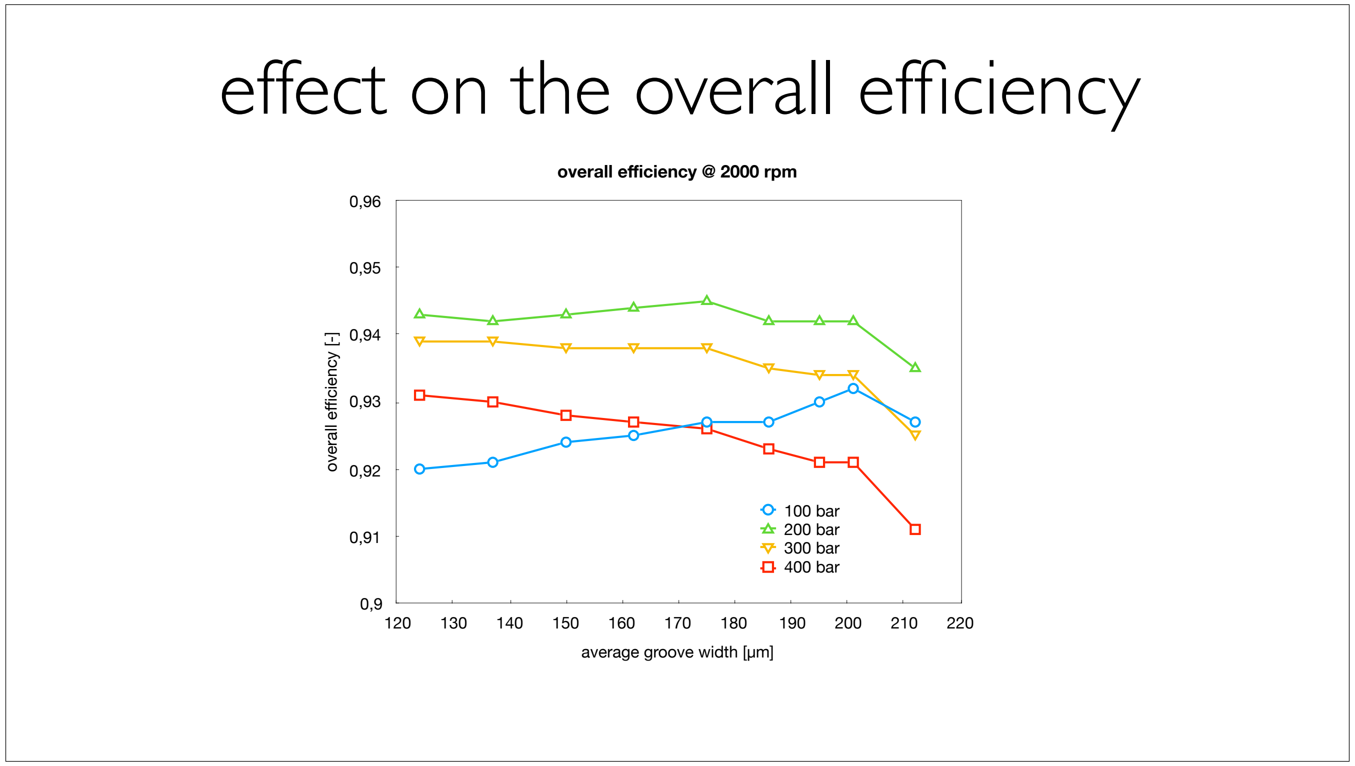
The second diagram, on the right, shows the friction of the barrel due to its rotation on the port plate. As you can see, the friction is increased due to the reduction of the groove size. A smaller groove reduces the pressure in the pocket which reduces the gap height, and hence, increases the viscous friction.

But you can also see that the friction is lower at higher pressures. This is due to the effect that pocket pressure has a stronger balancing effect when the pressure level is higher.

effect on the overall efficiency

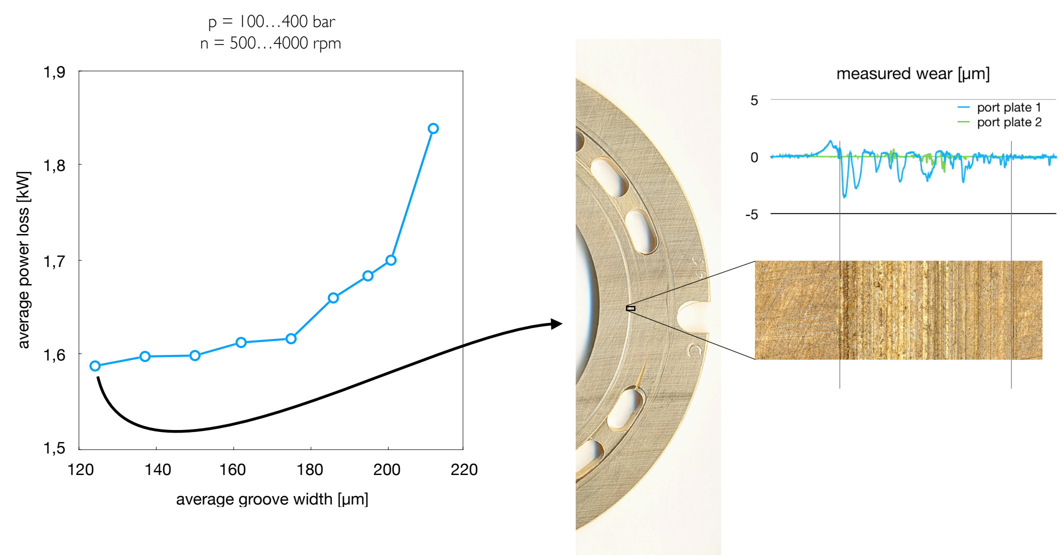


If we combine the two effects we get a view on the effect of the groove size on the overall efficiency. As you can see, at 100 bar, the overall efficiency reduces when the grooves are made smaller.



But when the pressure gets higher, it becomes beneficial to reduce the groove dimensions. Now these diagrams are for a rotational speed of 2000 rpm. We also performed measurements at other rotating speeds…

Average power loss



and calculated the average power loss. As you can see there is a big gain in the first reductions of the groove size.
However, below a width of 180 micron, the effects diminish.
We also monitored the wear of the port plate. We didn't have any wear until the average width was reduced to 124 micron. At that point we measured some wear at one of the port plates.
This is were our experiments stopped.

Conclusions

What have we learned?

Conclusions

- the grooves have an influence on the volumetric losses:
  - A smaller flow area results in reduced leakage

As expected, the dimensions of the grooves influences the efficiency and power losses of the pump.
A smaller flow area of the grooves reduces the leakage

Conclusions

- the grooves have an influence on the volumetric losses:
  - A smaller flow area results in reduced leakage
- the grooves have an influence on the torque losses:
  - A smaller flow area results in more friction

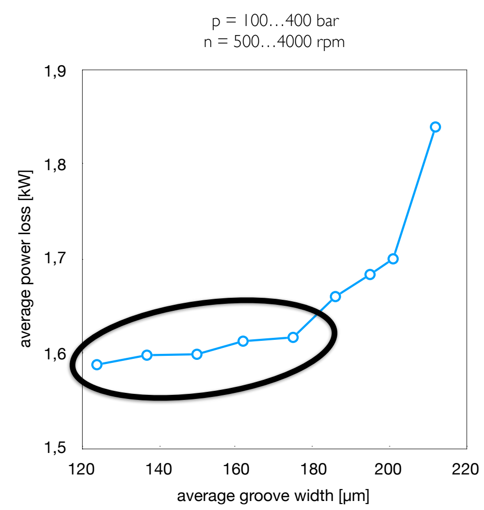
but is also results in higher friction losses

Conclusions

- the grooves have an influence on the volumetric losses:
  - A smaller flow area results in reduced leakage
- the grooves have an influence on the torque losses:
  - A smaller flow area results in more friction
- the grooves have an influence on the overall efficiency:
  - for most operating points a smaller flow area results in a higher efficiency

In the end these two effects cancel each other, as long as the grooves don't get too large.

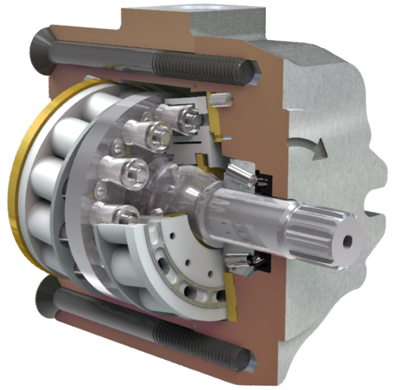
Conclusions



The grooves don't need to be manufactured with high precision

This is good news. It means that the overall losses on average are not dependent very much on the precise dimensions of the groove, and that the grooves don't need to be manufactured with high precision.

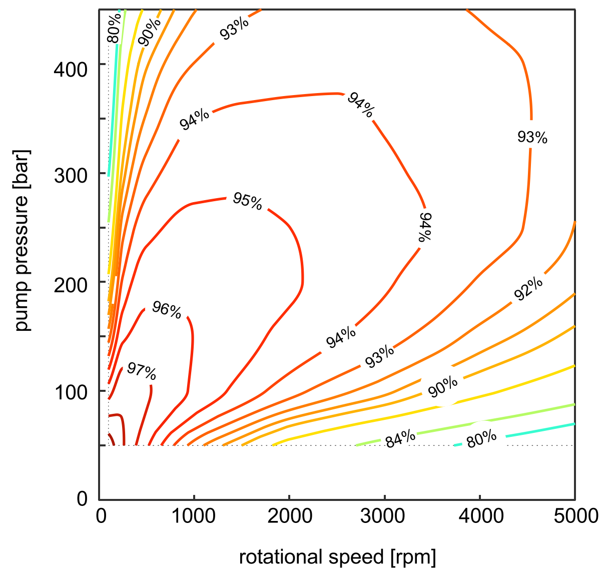
final test



- 153 points of operation
- 0,23 rpm … 5000 rpm
- 50 bar … 450 bar

At the end of this project we performed a final test, measuring the performance in a wide range of operating conditions

final test



- peak efficiency: 98%
- almost no friction at n ≈ 0 rpm
- high max. speed & pressure

The results are show here in this contour plot. We managed to increase the peak efficiency to 98% and to have an efficiency of more than 92% in most of the operating conditions. But we also managed to have no wear at the port plates. And to allow the pump to run at high rotational speeds, even at high pressure levels. We want to proof that a pump can be as good as an electric generator or even as a gears transmission.

[redacted]