Measuring the effect of shuttles

on the overall efficiency of a slipper type axial piston pump

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Presentation of Peter Achten about the measurements of the performance of a slipper type pump, before and after having shuttles applied.

this presentation

- we found a way to improve the efficiency of hydrostatic pumps and motors
- 'shuttles'
- this presentation: **test results**
- overall efficiency has increased by 3,4% on average – 4,5% in the peak
- the peak efficiency was increased to 96,4%
- a small step compared to what needs to be done

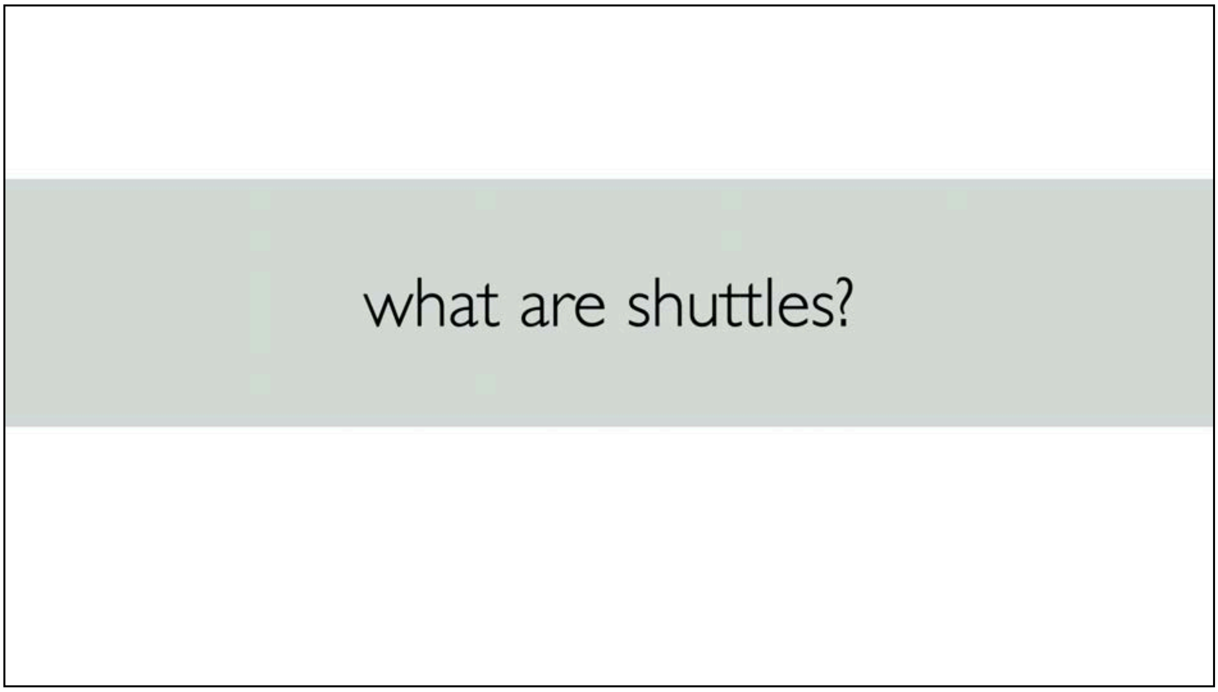
We found a way to improve the efficiency of hydrostatic pumps and motors. We called the solution 'shuttles'. In a minute I will explain to you what shuttles are and what they do.

We implemented the new solution in a conventional slipper type pump.

This presentation is about the test results. About measurements of the performance of the pump, without and with shuttles applied.

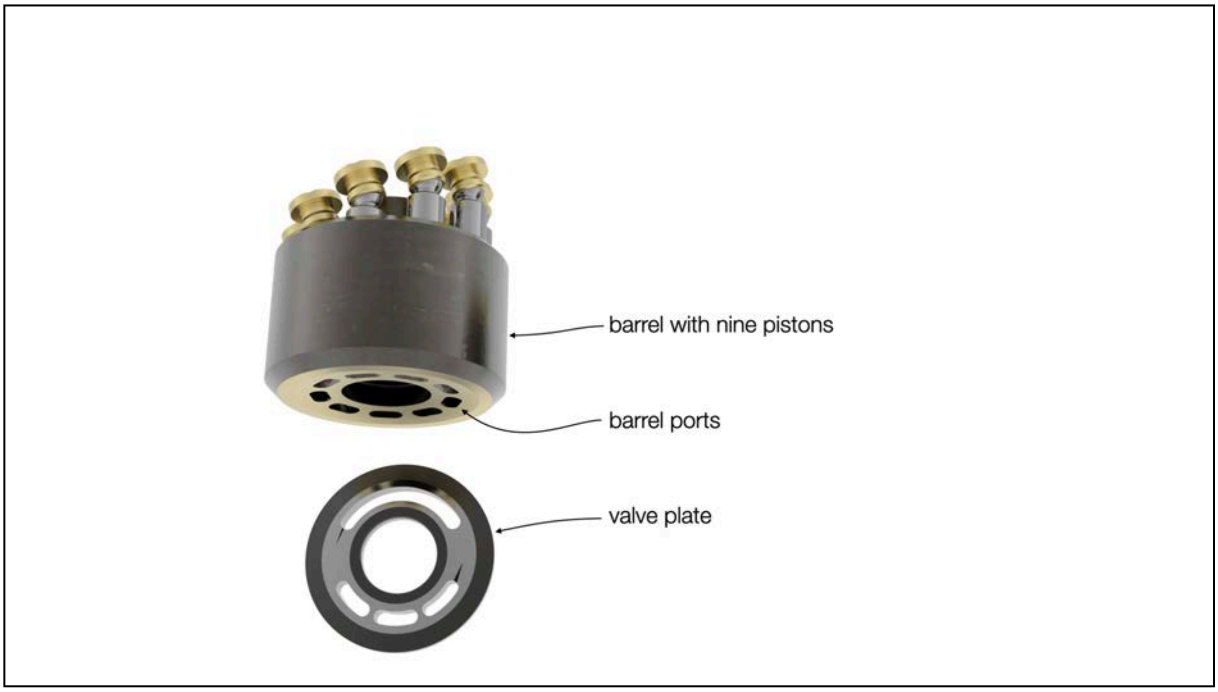
As we expected on the basis of our simulations, the shuttles indeed increased the efficiency. On average, in a large range of operating points, the overall efficiency was increased by 3,4%. The peak overall efficiency was increased by 4,5%, resulting in a peak efficiency of 96,4%.

We know, that will not safe the world. It is just a small step compared to what needs to be done.



Nevertheless, let's have a closer look at this new solution. What are shuttles?

Last year, I already explained the shuttle idea in a presentation. Maybe some of you have already seen this presentation. But for those who haven't, I will briefly explain again how the shuttle-solution looks like.



Let’s start with the cylinder block –or barrel– of an ordinary slipper type pump. Inside we have nine cylinders, in which pistons move up and down. Oil is flowing in and out of these cylinders, through the barrel ports. The whole thing, the barrel and the pistons, rotates on top of a valve plate.

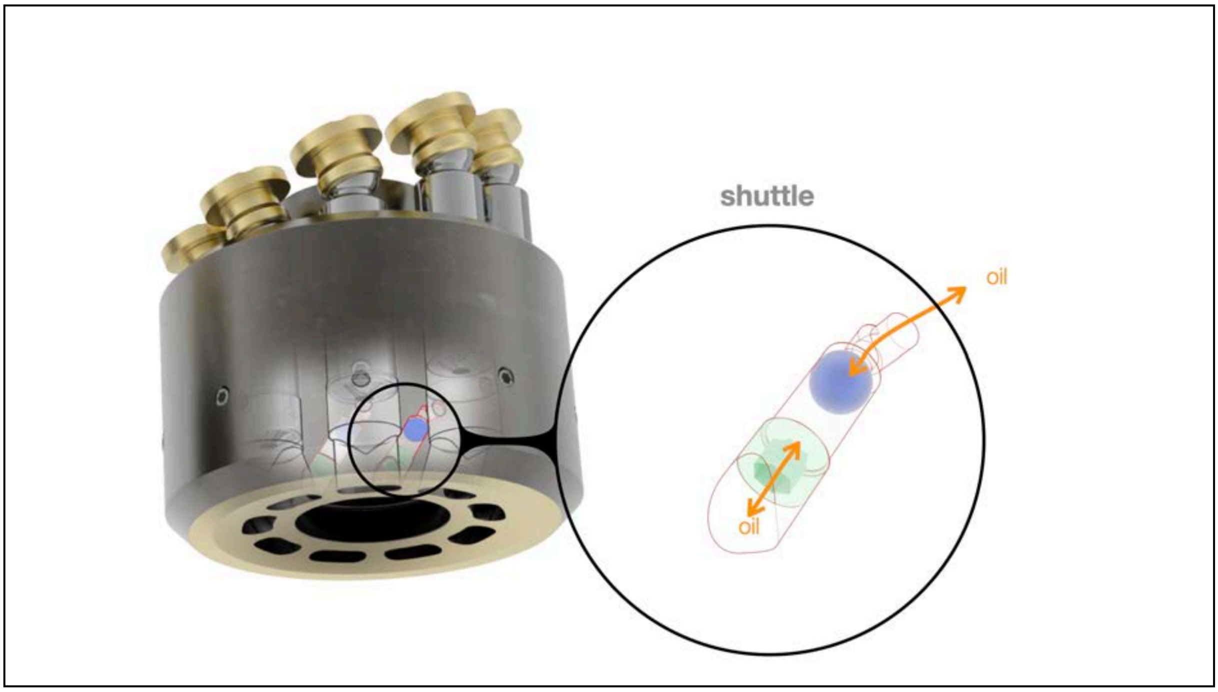
We have made three, rather small changes to this design.

First of all, we completely removed the silencing grooves from the valve plate.

The second change is that we increased the size of the sealing lands. When a barrel port is blocked by the sealing land, there is no connection to either the low or high pressure side of the pump. As a result, the oil in the cylinder will be compressed or expanded due the piston movement and the blocked barrel port.

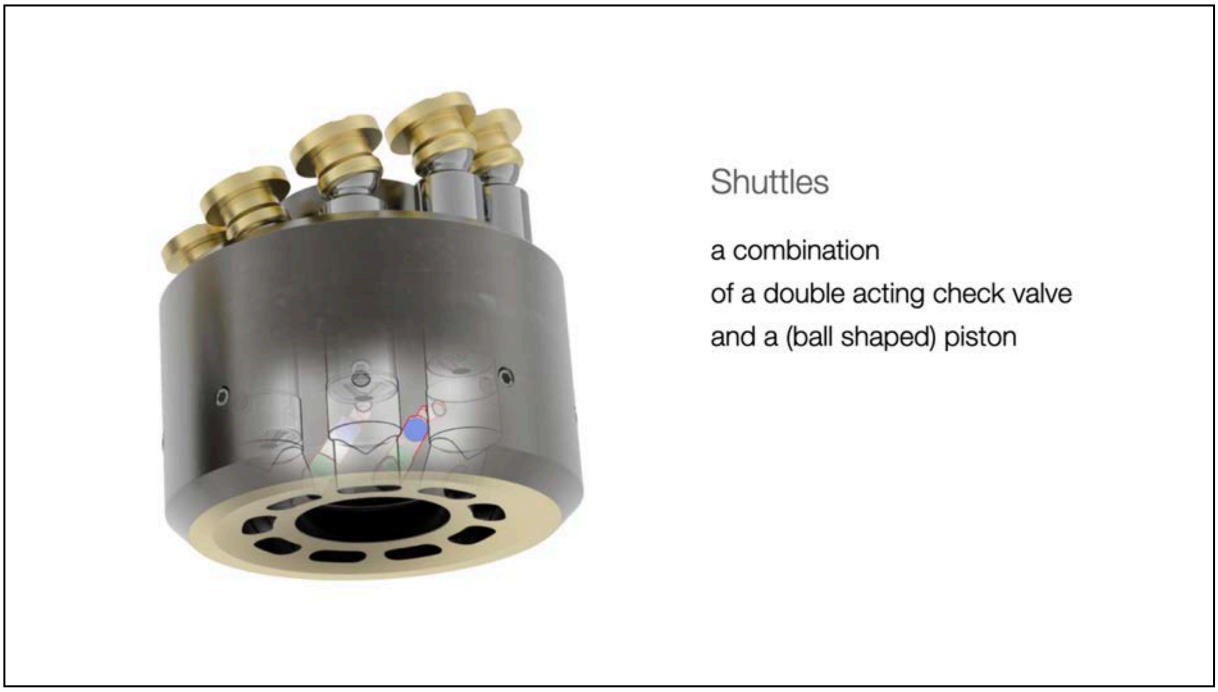
In the new design, these sealing areas are significantly larger.

The third change is not in the valve plate, but in the barrel. We made new connections between the cylinders inside the barrel. We call these connections shuttles.

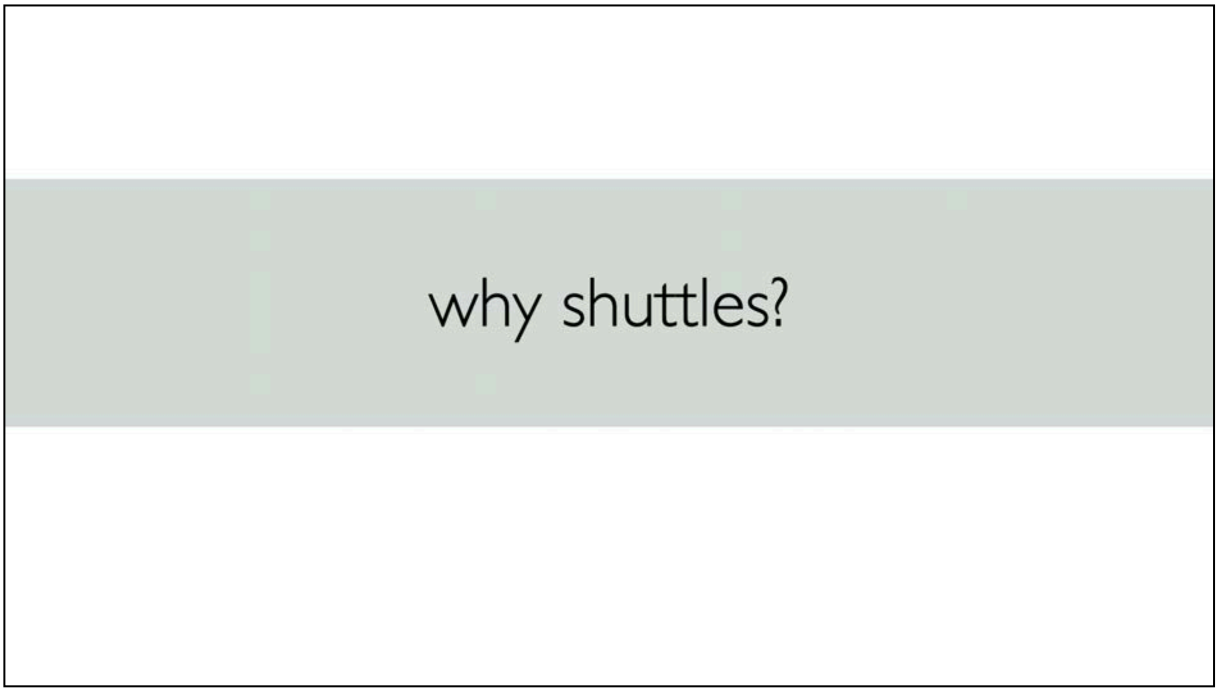


Each shuttle consists of a small cylinder in which we put a small ball. Finally we close the shuttle cylinder by means of a hollow plug.

This way, the shuttles will have two seats, one at each end of the shuttle The shuttle ball can only move back and forth inside its cylinder, cylinder, and while the ball moves, oil flows in and out of the shuttle.



Shuttles act as check valves when the ball is pressed into one of the two seats. But the ball also acts as a small piston, when it is moving from one seat to the other.



But why? Why should you consider using shuttles?

Shuttles, as such, don't improve the pump performance. It is the new design of the valve plate which creates the higher efficiency. But without shuttles, the new valve plate could not be used.

why shuttles?

- enable a different valve plate design
  - larger sealing land areas
  - no silencing grooves or pressure relief grooves
- elimination of commutation losses
- softer more gradual compression and expansion

Shuttles are an enabling technology. Shuttles create the opportunity to change the design of the valve plate: to increase the size of the sealing lands, and to get rid of the silencing grooves.

These changes make the pump much more efficient. Commutation losses are strongly reduced or even completely eliminated.

Moreover, the compression and expansion is softer and much more gradual, which creates new opportunities for noise reduction.

test results

Now let's move to the test results.

Test procedure

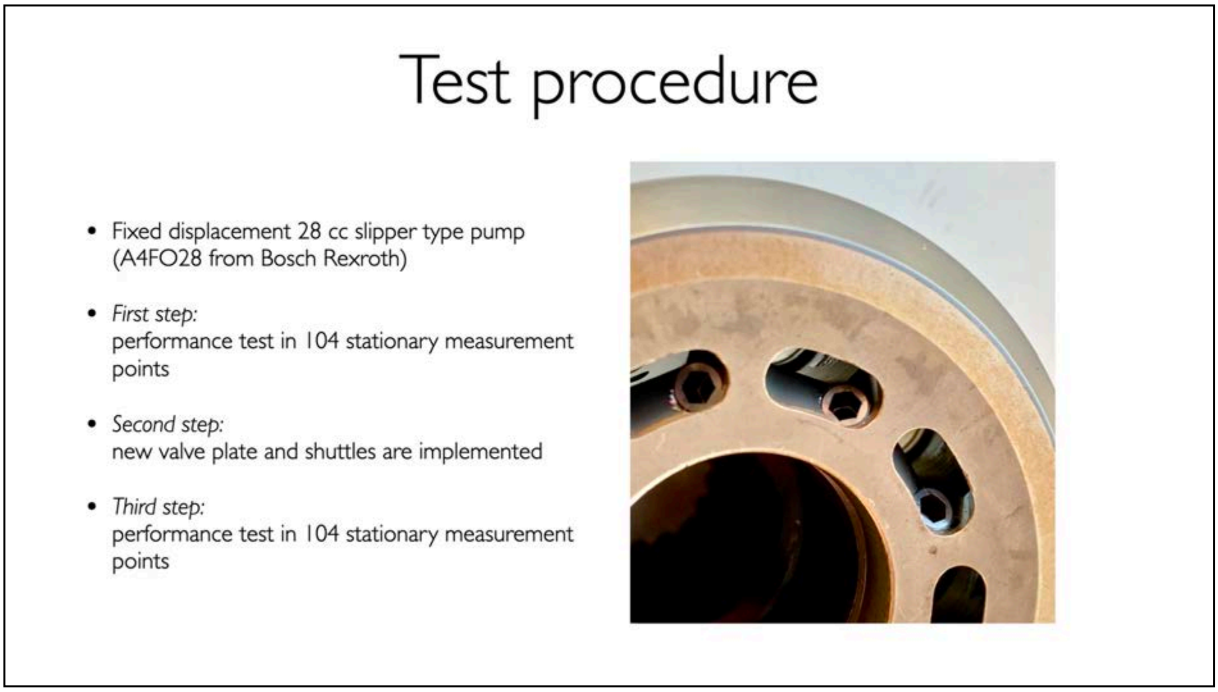
- Fixed displacement 28 cc slipper type pump (A4FO28 from Bosch Rexroth)
- *First step:*
  performance test in 104 stationary measurement points

104 measurement points

	pump pressure p_2							
	50 bar	100 bar	150 bar	200 bar	250 bar	300 bar	350 bar	400 bar
10 rpm	✓**	✓**	✓**	✓**	✓**	✓**	✓**	✓**
25 rpm	✓	✓*	✓*	✓**	✓**	✓**	✓**	✓**
50 rpm	✓	✓	✓	✓	✓	✓	✓*	✓*
100 rpm	✓	✓	✓	✓	✓	✓	✓	✓
250 rpm	✓	✓	✓	✓	✓	✓	✓	✓
500 rpm	✓	✓	✓	✓	✓	✓	✓	✓
1000 rpm	✓	✓	✓	✓	✓	✓	✓	✓
1500 rpm	✓	✓	✓	✓	✓	✓	✓	✓
2000 rpm	✓	✓	✓	✓	✓	✓	✓	✓
2500 rpm	✓	✓	✓	✓	✓	✓	✓	✓
3000 rpm	✓	✓	✓	✓	✓	✓	✓	✓
3500 rpm	✓	✓	✓	✓	✓	✓	✓	✓
3750 rpm	✓	✓	✓	✓	✓	✓	✓	✓

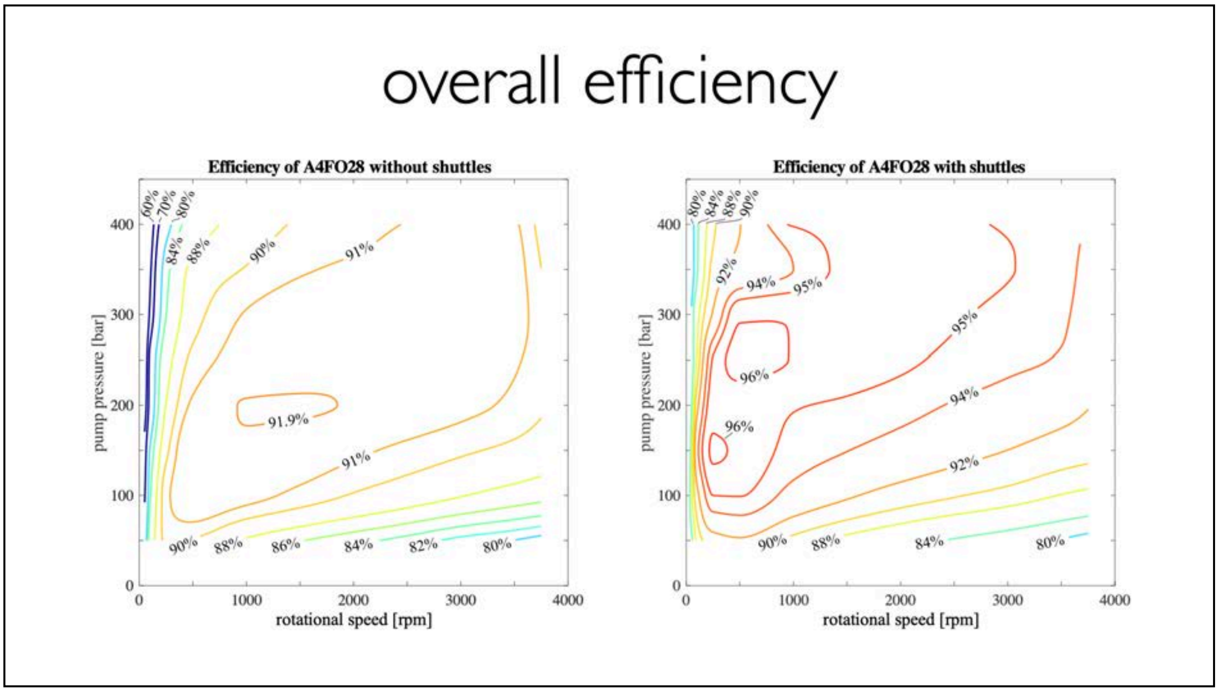
For the tests, we used a conventional slipper type pump, having a fixed displacement of 28 cc per revolution.

We tested this pump, without any changes, in a large number of stationary operating points.



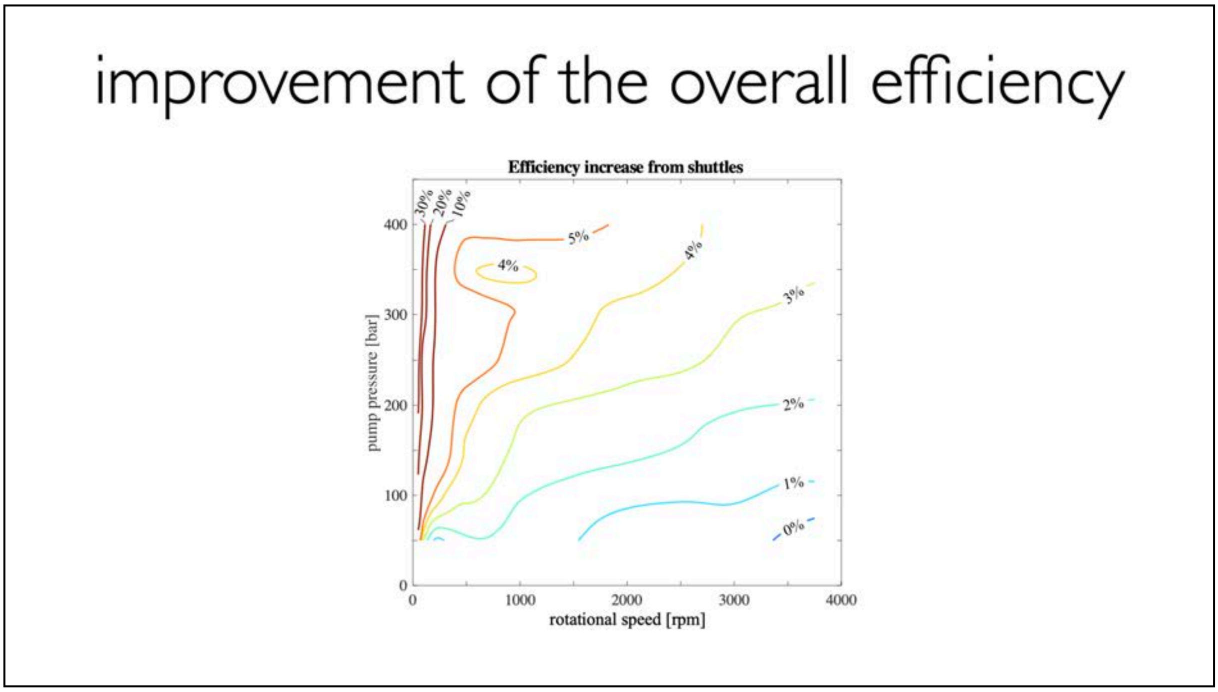
Then, after these measurements, we converted the barrel and the valve plate, leaving the rest of the pump as it was. In the barrel we applied nine shuttles, one between each pair of cylinders. In addition, we changed the design of the valve plate as I showed to you earlier in this presentation.

After this, we ran the same performance tests as before.



The left diagram shows the measured, overall efficiency of the pump, without shuttles applied. The efficiency peaked at around 92%.

The second diagram, on the right, shows the efficiency after the shuttles have been applied. As I have mentioned before, we only changed and replaced the valve plate and adapted the cylinder block for having shuttles. The rest of the pump remained the same. This way, the change of the efficiency is completely due to the shuttles and the new valve plate.

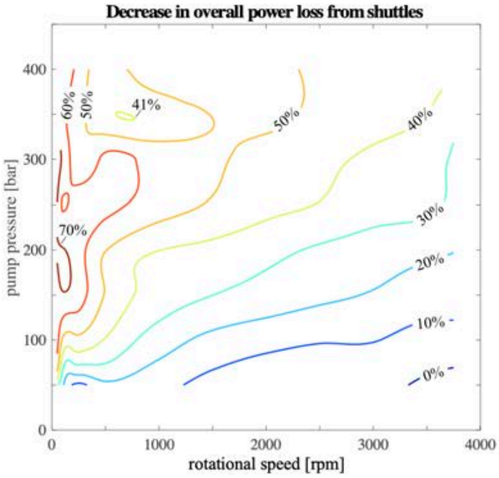


If we subtract both plots we get this diagram, which shows the improvement of the overall efficiency in %-points.

At low pump pressures and high rotational speeds, the shuttles offer no improvement.

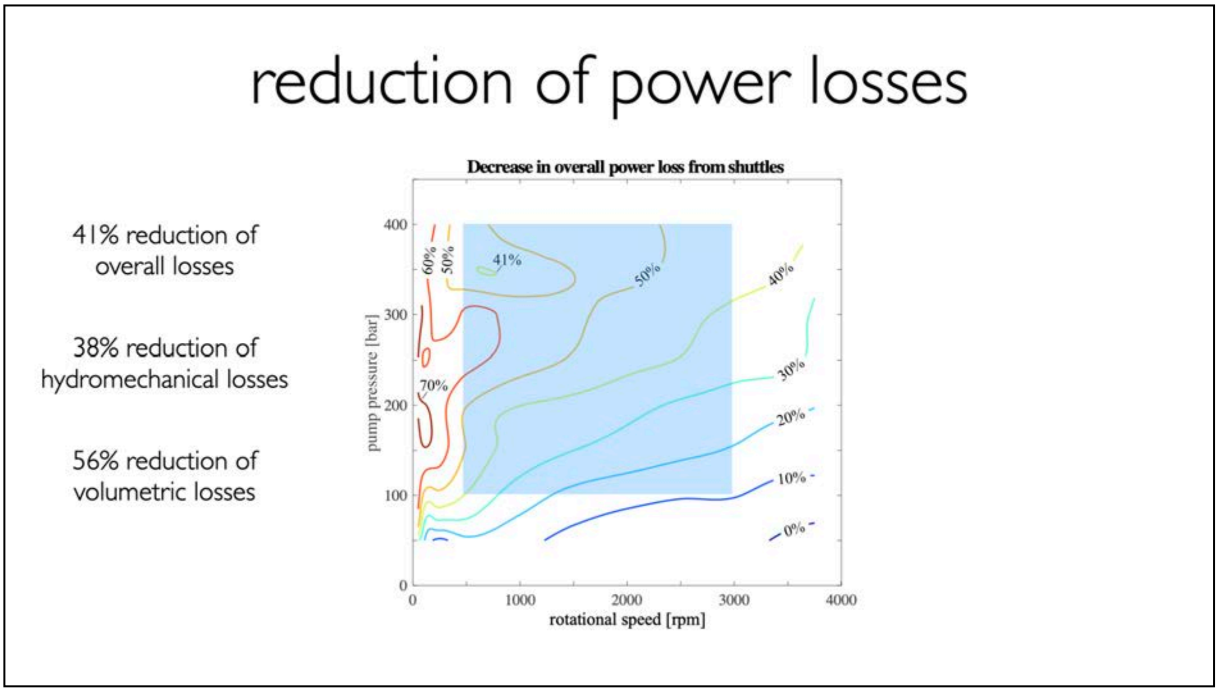
But at higher pump pressures, and especially at lower pump speeds, the improvements are substantial. In some points, the efficiency is improved by more than 30%-points.

reduction of power losses



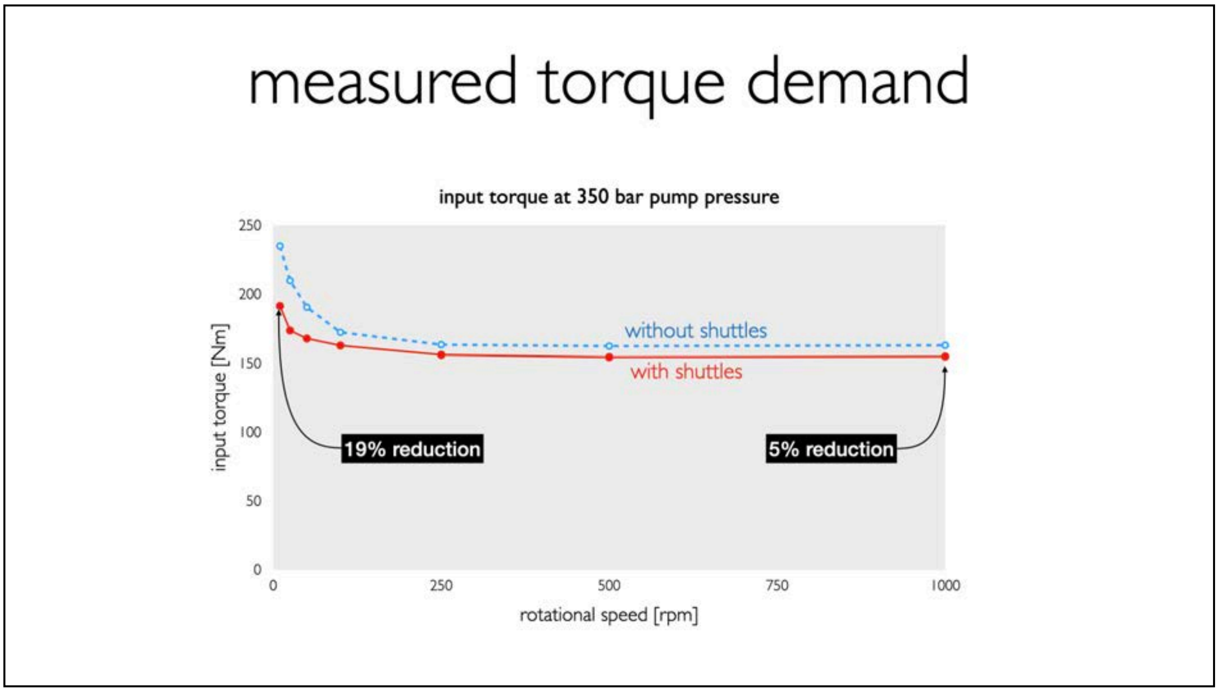
This plot shows the reduction of the overall power loss that results from the adapted pump design.

In some points, the power losses are reduced by as much as 70%.



In order to calculate average values, we –rather arbitrarily– defined this blue area as an area, where we consider that most of the pump operation might be.

On average, in this blue area, the overall losses of the pump have decreased by 41%. Both the hydromechanical losses and the volumetric losses have been reduced. The hydromechanical losses by 38% and the volumetric losses by 56%.



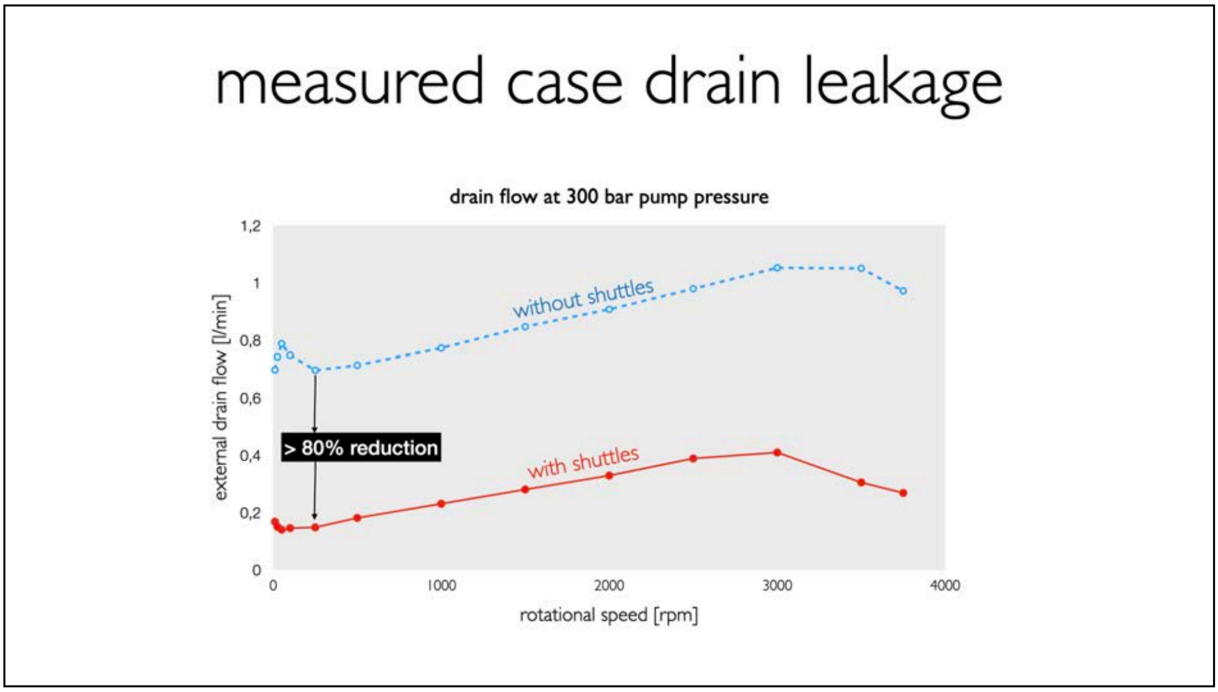
Let's have a closer look at the hydromechanical losses. Here you see the measured input torque, at a pump pressure of 350 bar for rotational speeds below 1000 rpm. The blue line represents the measurements of the standard pump, without the shuttles. At speeds below 250 rpm, the torque increases. This is generally due to a loss of hydrodynamic lubrication conditions.

The second line, the red line, shows the measurements after shuttles were applied. The measurements were performed at exactly the same operating conditions as before.

As you can see, the input torque is reduced by using shuttles. In most of the 350 bar measurement points, the reduction is about 5%. This is also what we expected. The reduction is due to a complete elimination of the commutation losses.

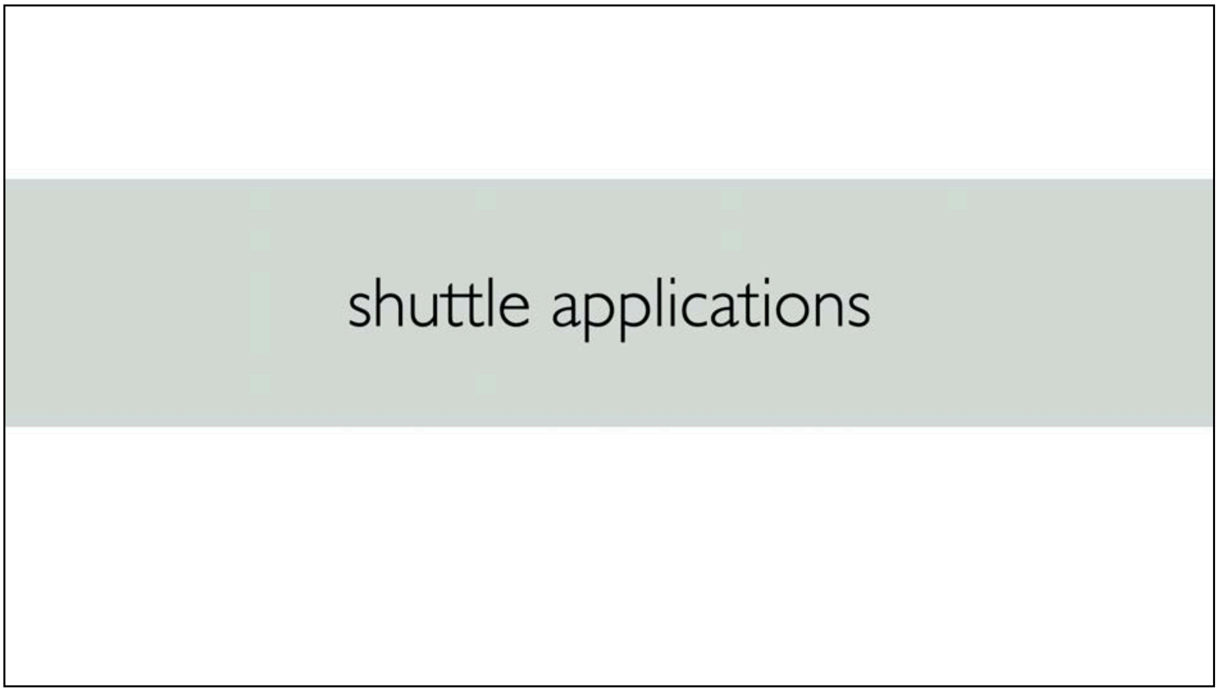
However, much to our surprise, the reduction of the input torque was much larger at low rotational speeds, up to 19%.

If this pump would be driven by an electric motor, the motor could be reduced in size by nearly 20%.

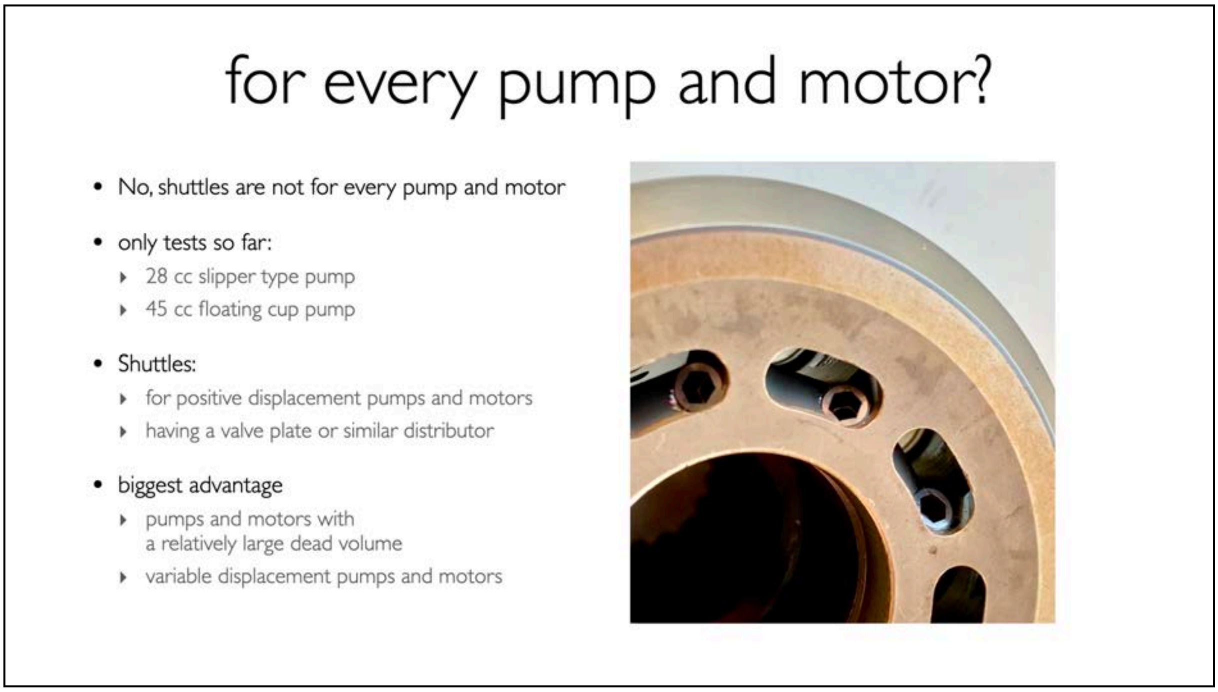


Another interesting test result was the leakage from the house; the case drain. This diagram shows the leakage flow we measured from the case, without and with shuttles applied. At low operating speeds, the leakage has been reduced by more than 80%.

I guess I don't need to explain to you how important the reduction of volumetric losses is for many hydraulic applications, especially for modern electro-hydraulic applications which are frequently operated at low rotational speeds.



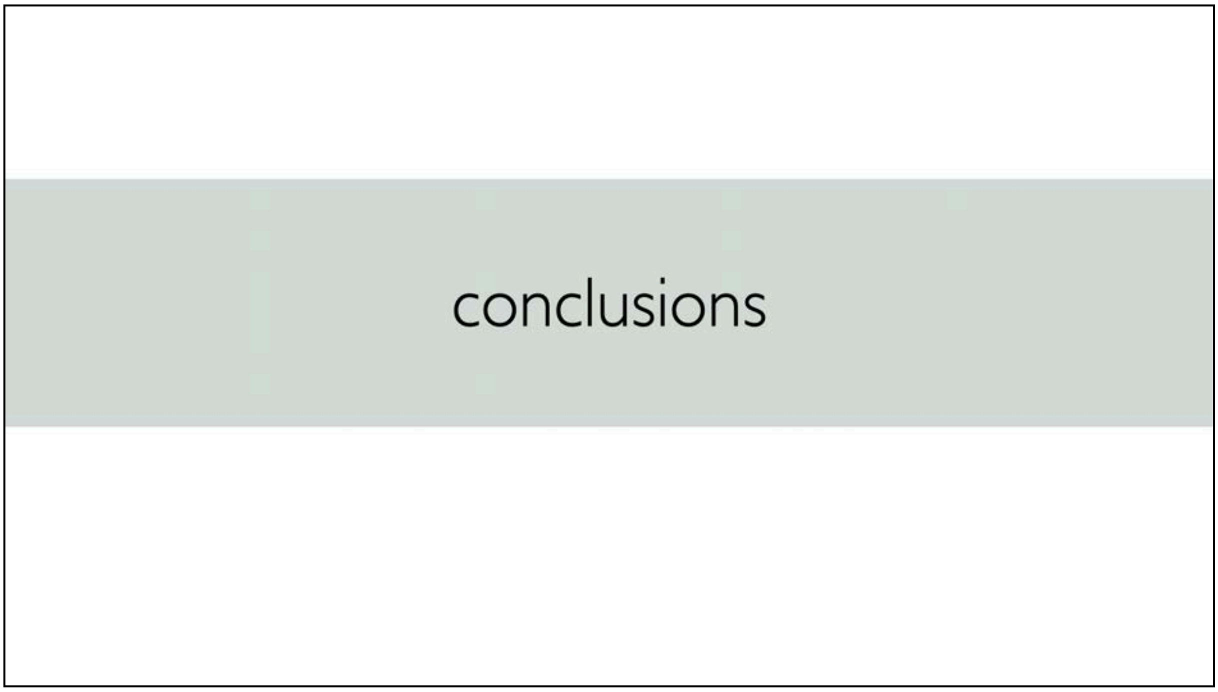
Now, these test results were the just benefits for a single pump. A slipper type pump. How about other pumps and motors?



Shuttles are not a general solution for all pumps and motors. So far, we only tested the shuttles in a 28 cc slipper type pump and a 45 cc floating cup pump.

In principle, shuttles can only be applied in positive displacement pumps and motors, having some kind of valve plate or similar distributor. Consequently, shuttles can also be applied in radial piston pumps. But not, for instance, in gear pumps.

The advantage of shuttles is biggest in pumps and motors with a relatively large dead volume. This is especially true for variable displacement machines in which the dead volume becomes relatively larger at smaller displacements.



To conclude.

conclusions

- significant improvement of the overall efficiency of conventional pumps and motors
- 41% reduction of overall losses
- strong improvements for rotational speeds below 1000 rpm
- peak efficiency of 96,4%
- near cost neutral solution

Shuttles give you the opportunity to increase the overall efficiency of many pumps and motors. The overall losses of the tested pump are decreased by 41%. For other pumps and motors with a larger dead volume, or with a variable displacement, the advantages will even be larger. To our own surprise, not only the commutation losses are reduced but also other friction losses and volumetric losses are decreased, especially for rotational speeds below 1000 rpm.

This is important for hydraulic motors, which often run at low speeds, but also for electro-hydraulic speed controlled pumps. The strong reduction of both torque and leakage will reduce the dead band of the control of these units.

Of course, the improved efficiency will have a direct effect on the battery size in the case of battery electric driven applications.

The peak efficiency of this slipper type pump has been increased to over 96%. Such a value could so far only be reached by the best bent axis pumps, and by floating cup pumps. With shuttles, this is already possible for a relatively small and simple slipper type pump.

We believe that the shuttles are a simple and near cost neutral solution. Yes, you will need to put some balls and shuttle cylinders in the cylinder block. But there are no strict tolerance constraints. In our tests, we used balls with a diameter of 4.5 mm in a shuttle cylinder with a diameter of 4.9 mm. Whereas the shuttles will indeed increase the costs, the valve plate design will be simplified, which results in a cost reduction.