

# Improving pump control

IO.IFK - Dresden, Germany



I N N A S

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Mr. Chairman, ladies and gentleman,  
good afternoon.

Perhaps, you expect me to give a very detailed, technical presentation about pump control. Well, in that case I have to disappoint you. I will not bother you with linearized models, Laplace transformations or Nyquist diagrams.

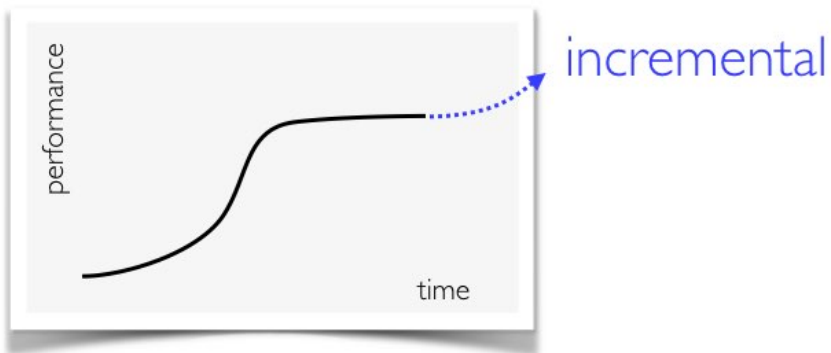
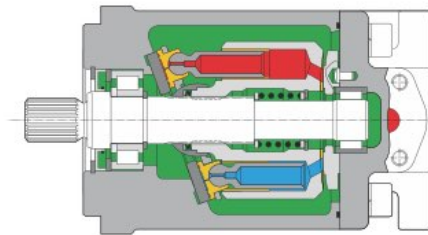
Of course, I will be most happy to discuss these later on with you, but, for today, my presentation is about...



INNOVATION

...innovation.

# types of innovation

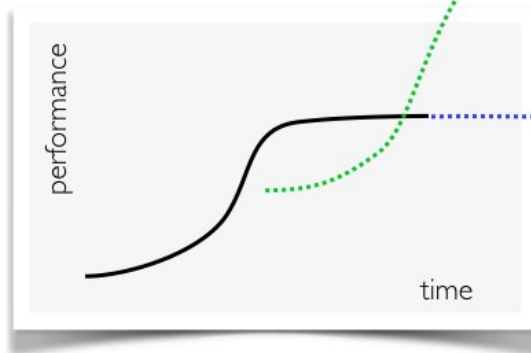
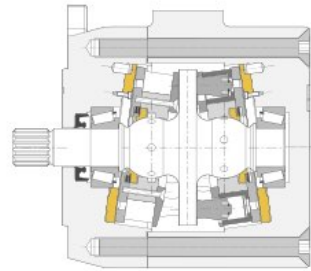


There are many types of innovations. A first category, are the so-called 'incremental innovations'. These are relatively small improvements of an already existing technology.

During this conference, many marvelous examples are presented, which belong to this category.

The advocates and supporters of this type of innovation are of the opinion, that many incremental improvements and small evolutionary steps are sufficient to secure the future of the pump industry.

# types of innovation



radical

old technology  
has reached its limit

I disagree with that. I don't see the swash plate as 'the key to the future'.

Instead, I believe that current hydrostatic principles have reached their limit, and that a radical innovation is needed to bring the hydraulic industry forward, to get it out of its isolated position and out of its market niches.

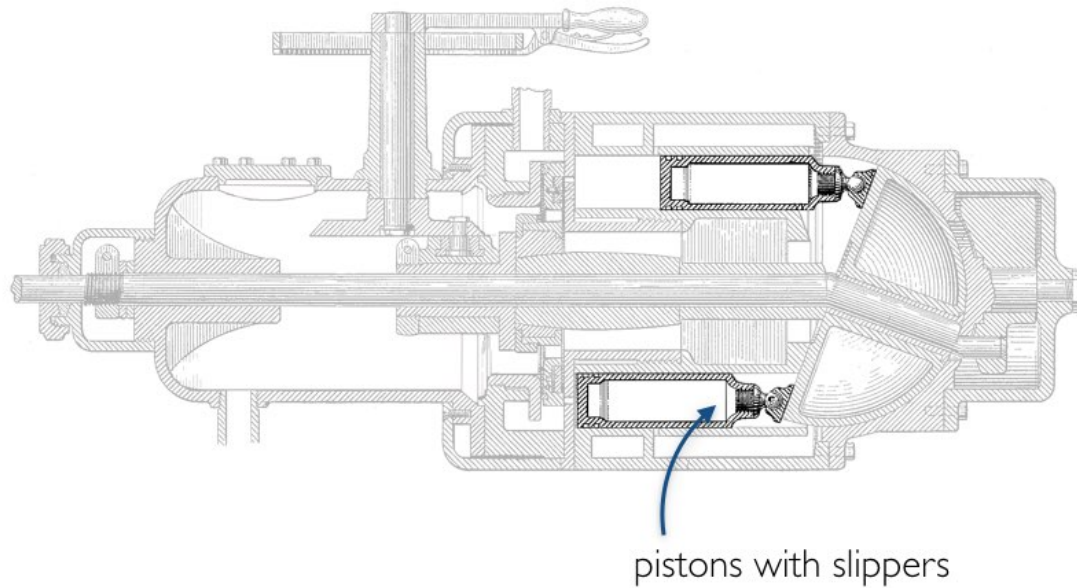
I believe that new design principles are needed, to finally address the demands of today's and tomorrow's customers worldwide.

And I am convinced, that only radical, new solutions will allow growth into new territories, markets and applications.

But, before discussing this in more detail, let me take a step back with you, and have a look at the evolution and lifecycle of the swash plate principle.

# the swash plate principle

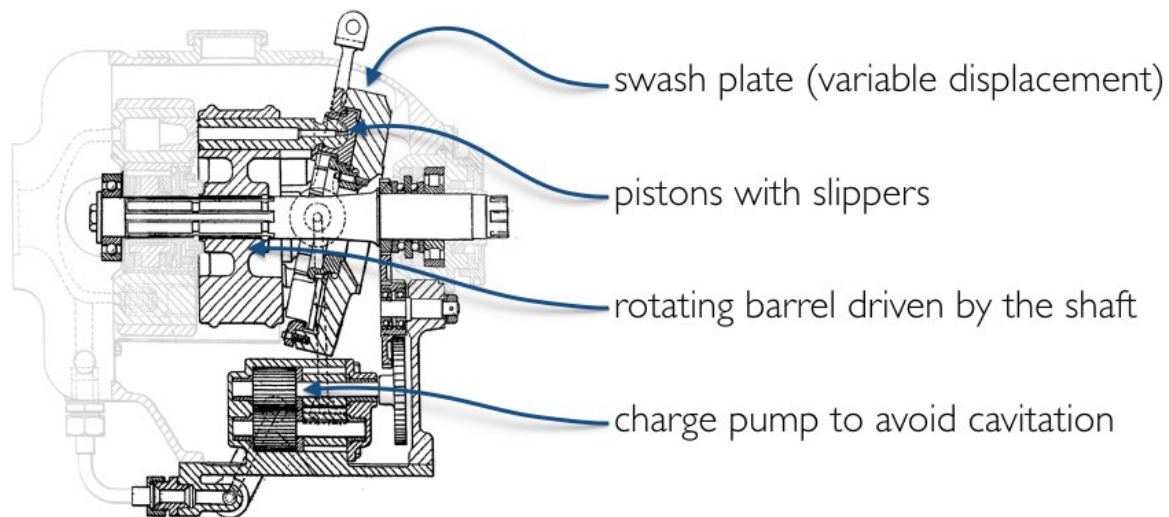
## Steam engine William Esty (1887)



This, is the oldest design I have found, of a machine with pistons and slippers running on a swash plate. It is a patent for a steam engine.

This design belongs to the very origins of the swash plate principle.

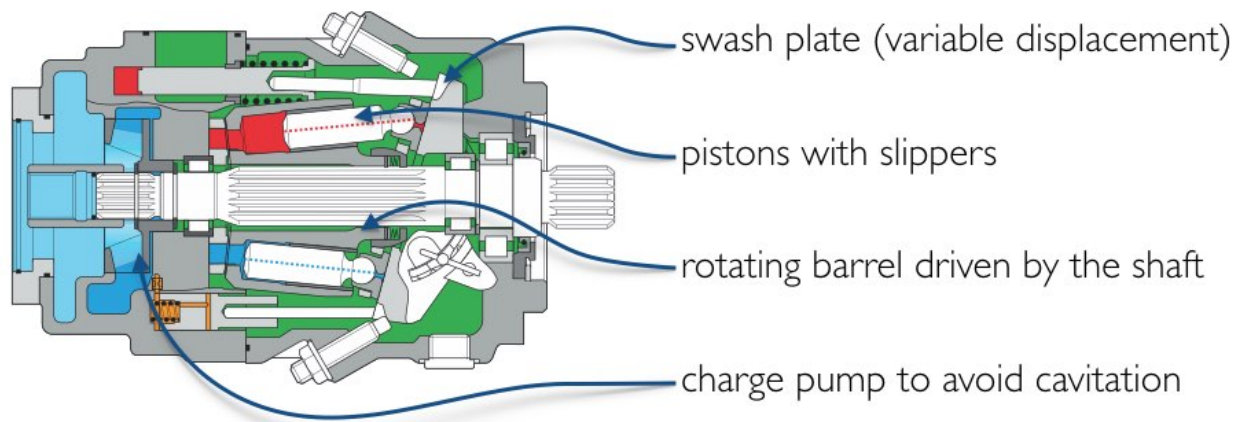
## Ingoldby (1923)



This design, for example, from 1923, shows all the elements of a modern pump:

- the swash plate, which can be rotated to change the displacement;
- the pistons and slippers;
- the rotating barrel, which is driven by the shaft;
- and even a charge pump, to avoid cavitation.

## Bosch Rexroth (2016)

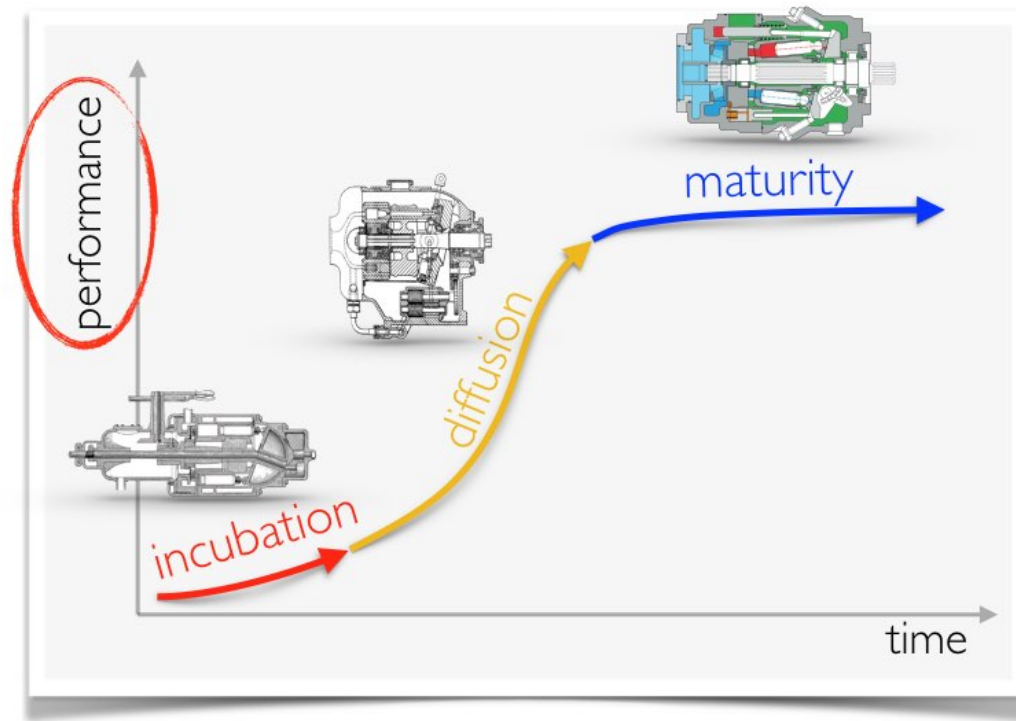


The same elements can be found in today's in-line axial piston pumps:

- a swash plate;
- a group of pistons, each having its own slipper;
- a rotating cylinder barrel, driven by the shaft;
- and –if needed– a charge pump.



# the product lifecycle

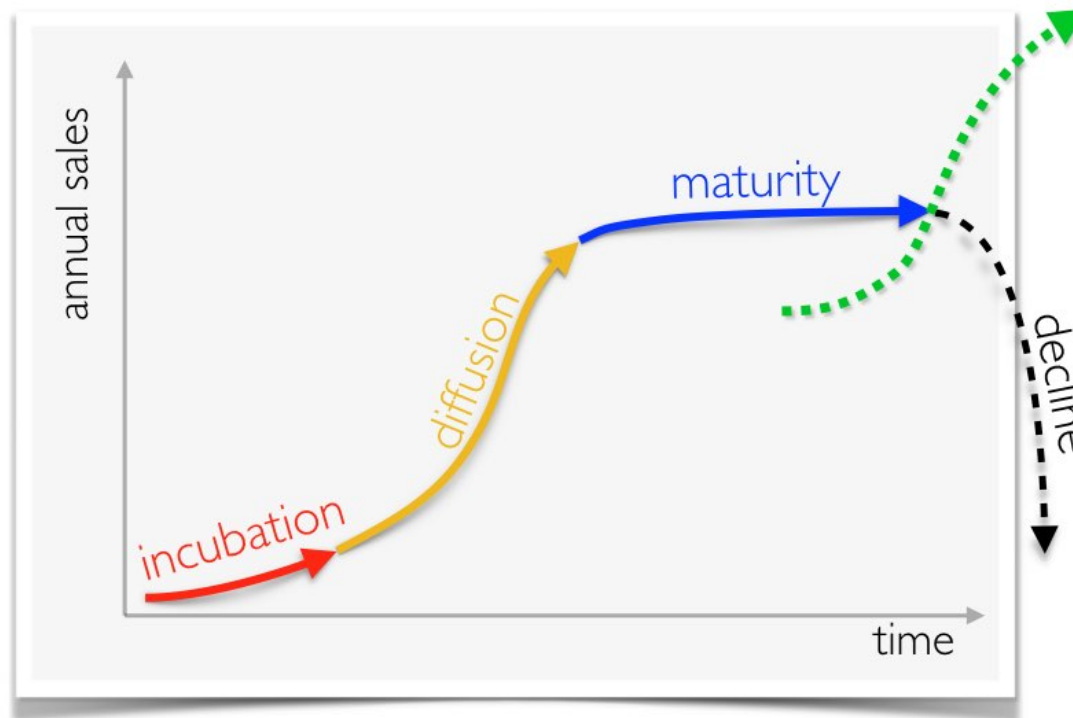


The previous three examples represent the various lifecycle phases of the swash plate principle:

- the incubation phase;
- the diffusion phase;
- and, finally, the maturity phase.

This diagram shows the improvement of the product performance over time.

# the product sales cycle



A similar diagram can be drawn, showing the total product sales per year.

As before there is:

- an incubation phase;
- a diffusion phase, which is characterized by its strong growth;
- and a maturity phase.

The diagram looks the same as the previous product lifecycle diagram. But, there is an important difference: this diagram has a fourth phase: the decline.

The decline happens when a new solution is offered to the market, which is outperforming the old technology.

# What to do when a technology is mature?

Yet, what happens when a technology, in this case the swash plate principle, has become mature and maybe even out of date? What is the response of current companies, and what is wrong with it? Let me try to explain this by means of a simple metaphor: a house

## Holland Island House



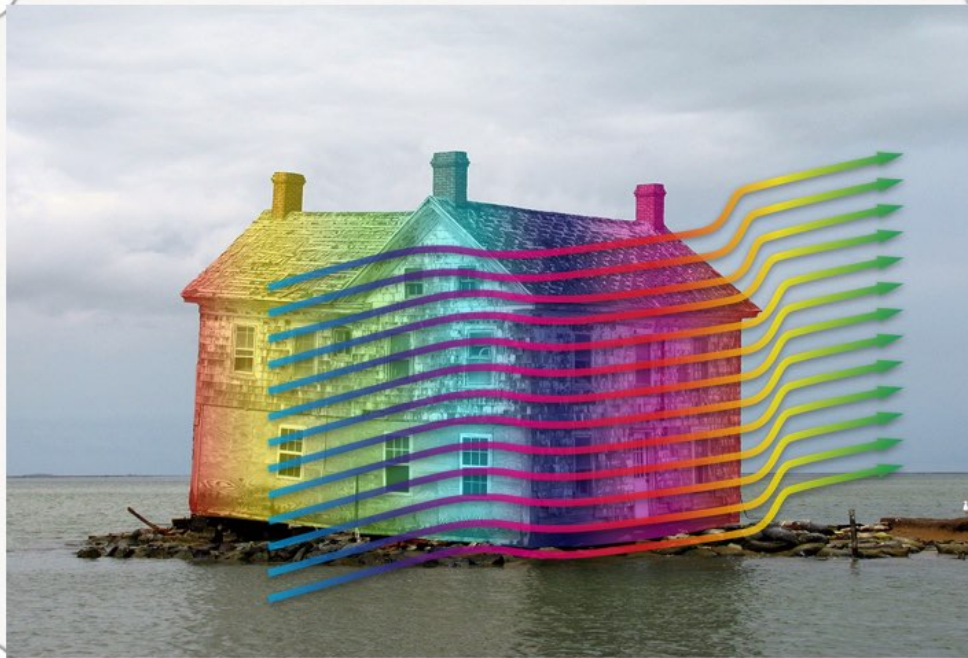
This is a picture of Holland Island House, close to Washington DC in the US. The house is about as old as the swash plate principle. It has been a wonderful place to live, and many generations grew up in this house.

But it is a bit worn down and sleazy, don't you agree? Now, suppose, you are still in the business of selling this 'product' (and remember, this is a metaphor!). What can you do?

Of course you can scare away the birds, rebuild the chimney of the right wing...



...perform numerous FEM-analysis  
and CFD calculations...







...have a new roof and repaint the walls.

And if that is still not enough, you can ultimately pimp it up, with some of the latest electronic devices and modern means of communication.

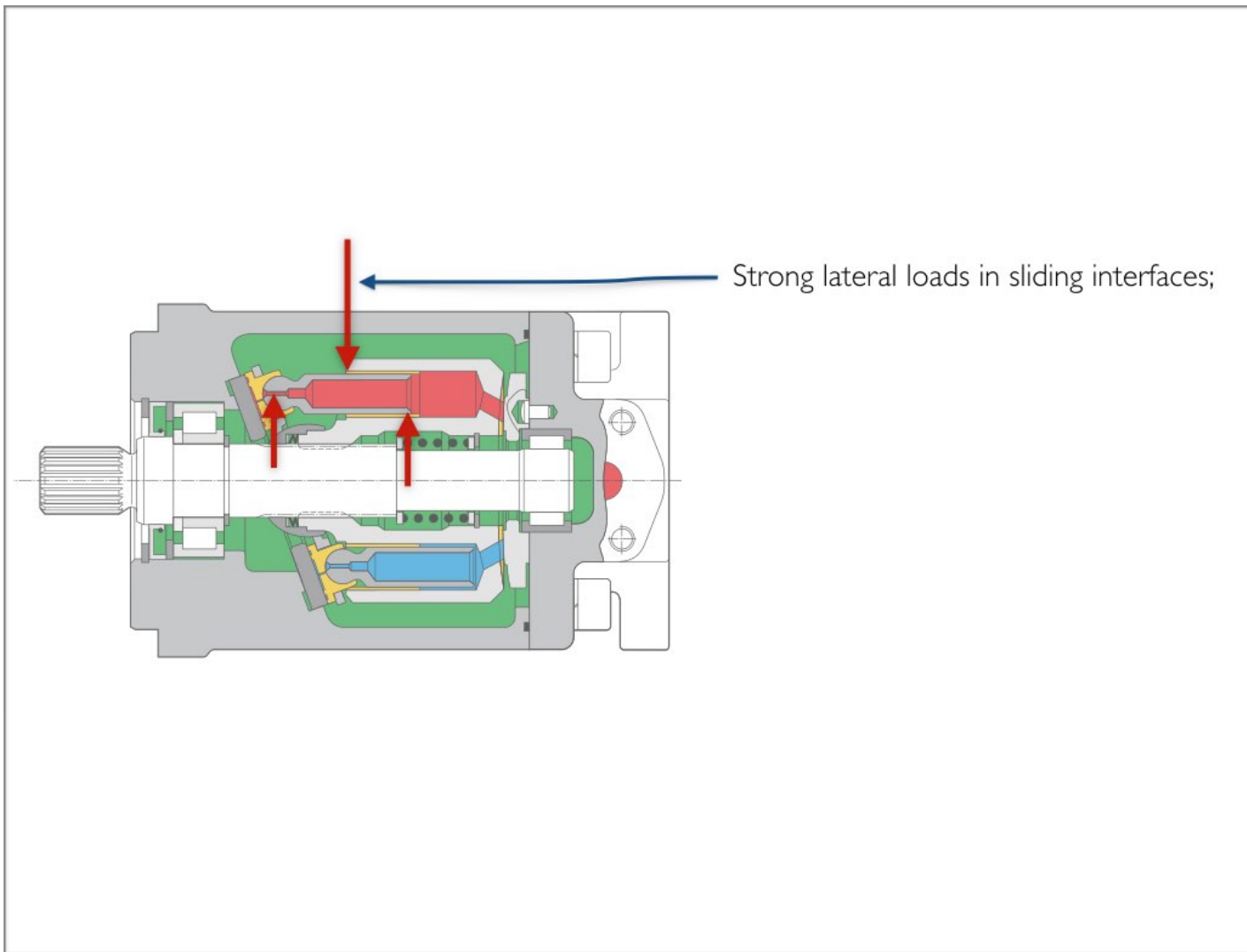


But, all this does not solve the key problem. It is still an old house with a rotten foundation that can not be replaced.

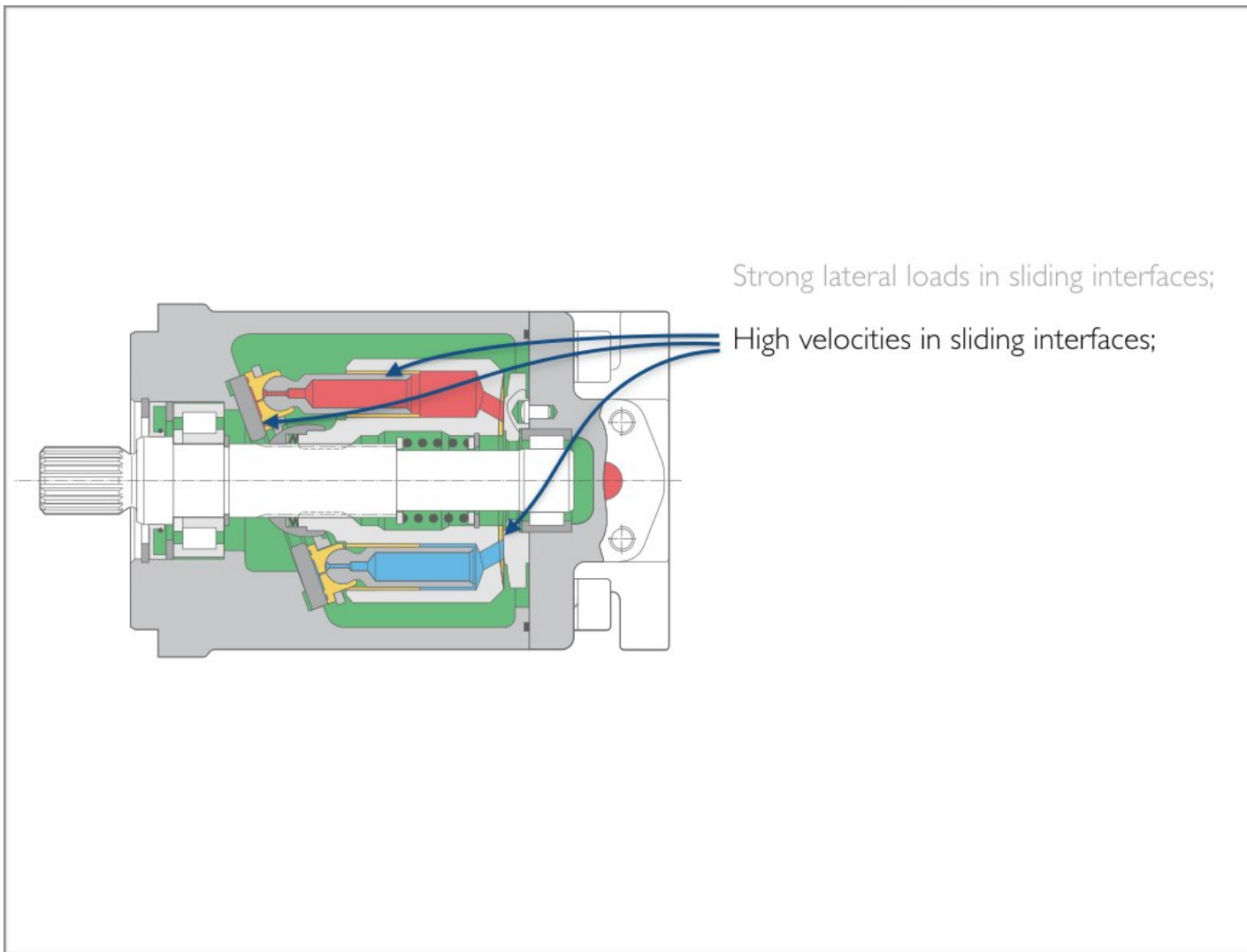


# swash plate limitations

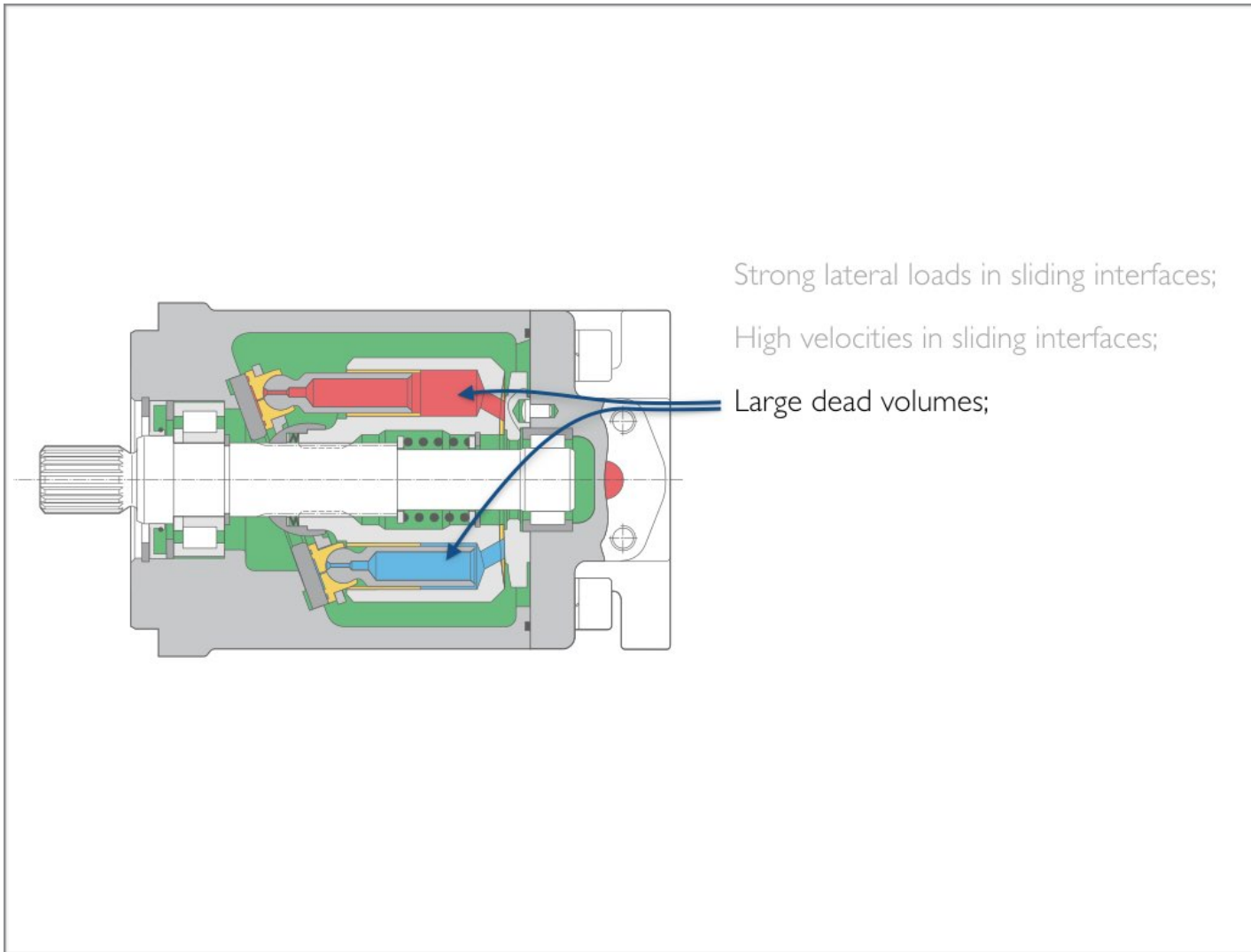
Now, considering that this was a metaphor, what does it tell about the life cycle and future of the swash plate principle? What exactly are its foundations and how rotten are they?



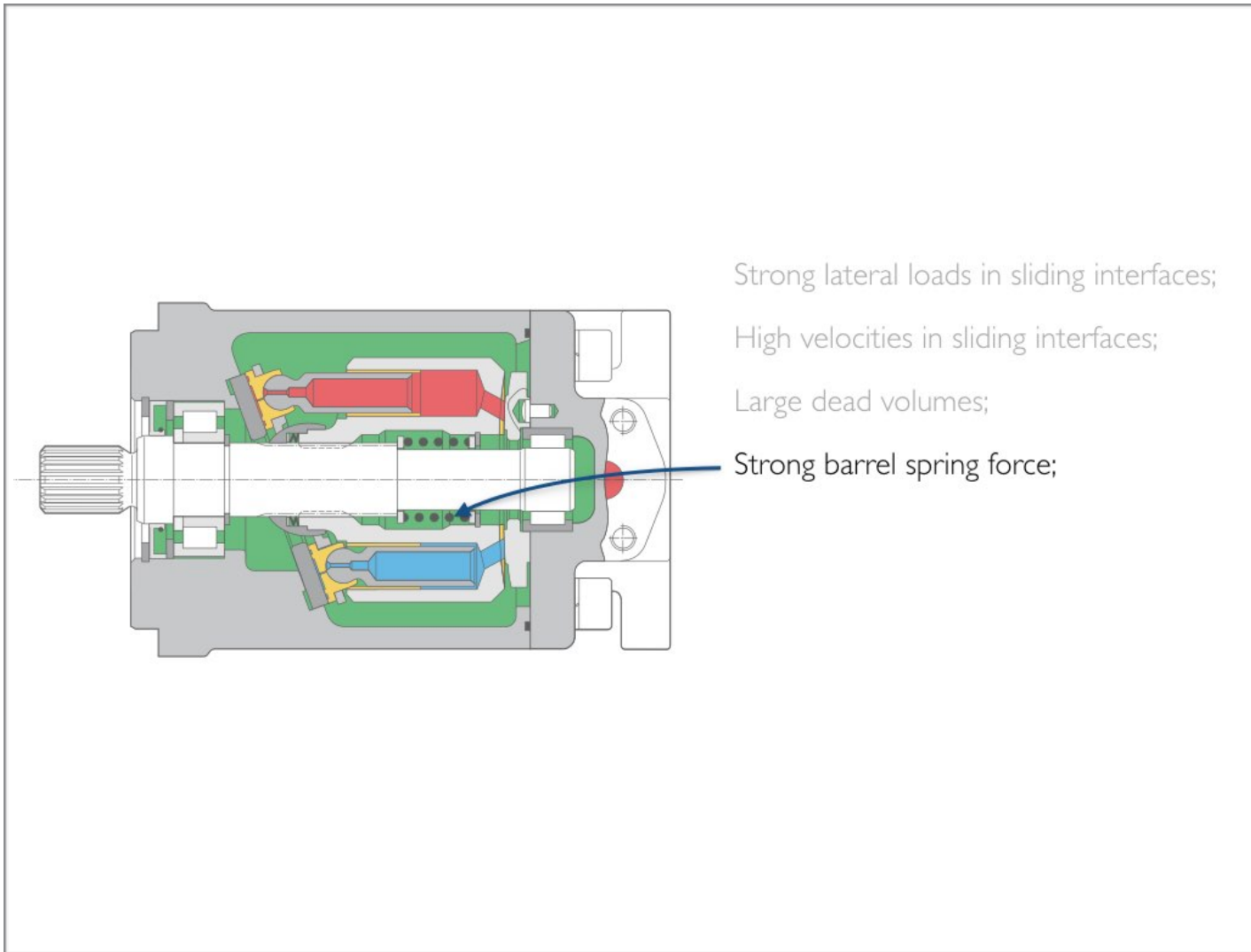
One of the key problems is of course the high load in the contact between the piston and its cylinder. The full hydrostatic power is transferred via these sliding contacts. This is most certainly, fundamentally wrong.



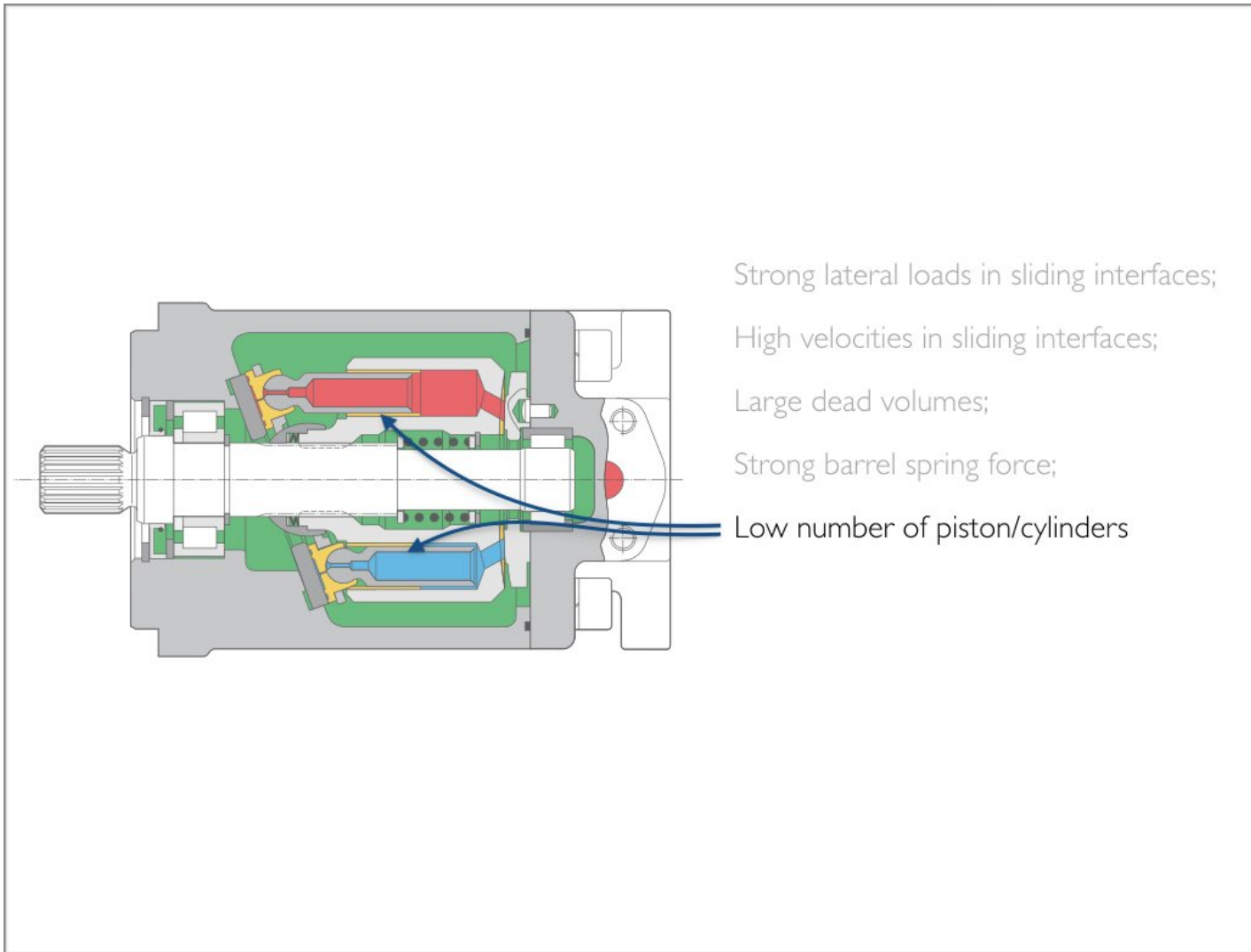
Piston pumps and motors are positive displacement machines. They always have sliding interfaces, and therefore always cause friction and wear. But, it is the combination of strong loads and high relative velocities that is the prime cause of high losses and strong wear in these machines.



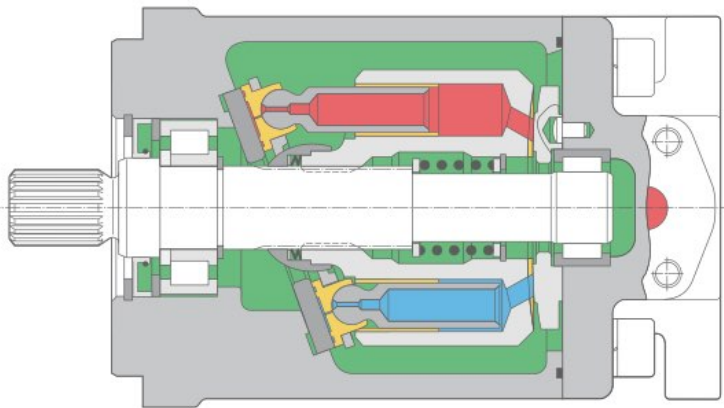
Dead volumes can also contribute to significant losses. The dead volume can be decreased, simply by having solid pistons. But this strongly increases the piston mass and the centrifugal forces, which, again, results in stronger friction losses and higher wear, but also in an increased tipping torque of the barrel.



This again, increases the required axial bearing force of the barrel, and thus further escalates the friction between the barrel and the port plate.



The swash plate principle is also characterized by a very limited number of pistons, typically being nine. The small number of pistons is a fundamental cause of noise, large flow and pressure pulsations and strong torque variations.



Strong lateral loads in sliding interfaces;

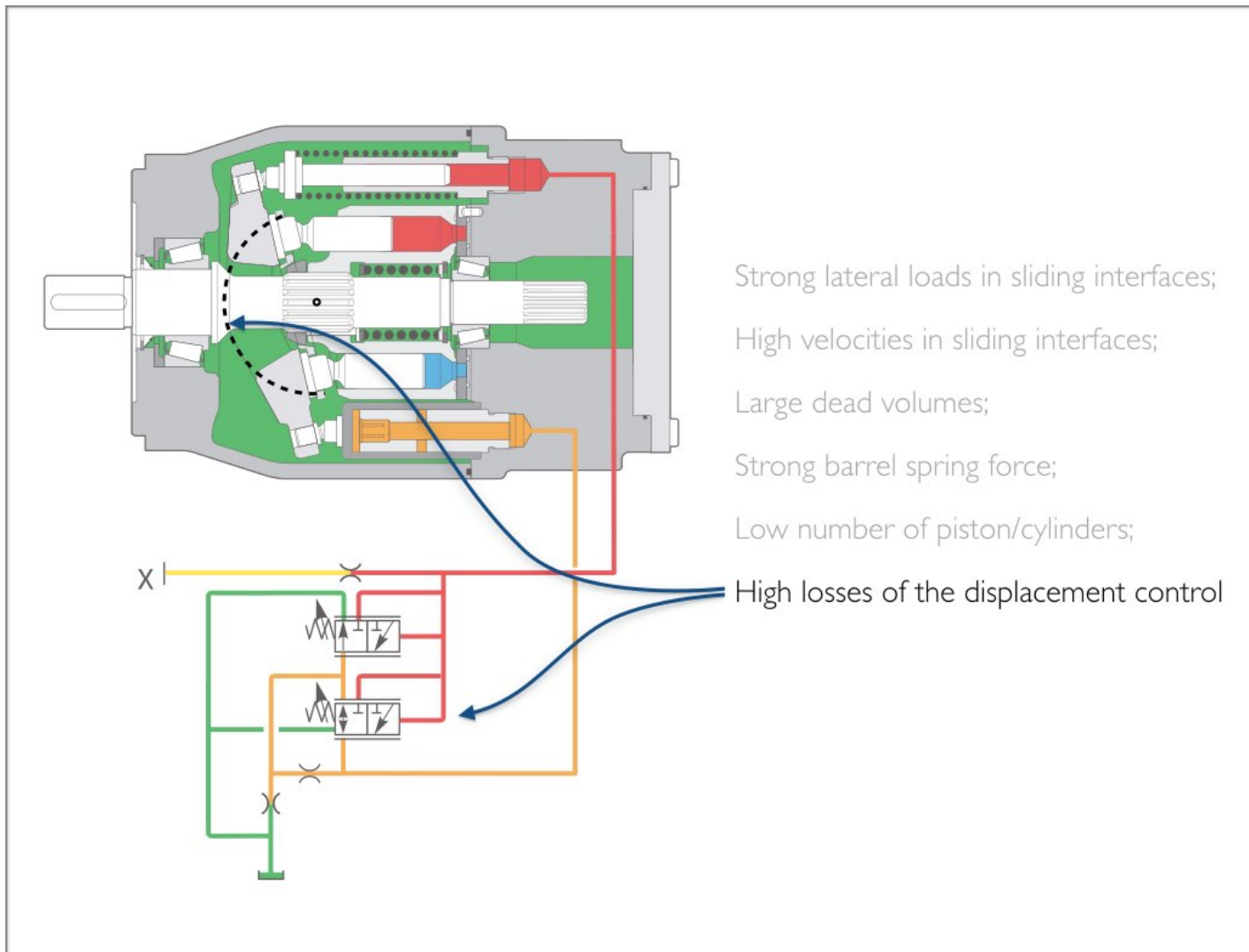
High velocities in sliding interfaces;

Large dead volumes;

Strong barrel spring force;

Low number of piston/cylinders

So...these are the rotten foundations, which are inherent to the swash plate principle. And let me add another one:



the control. The control of the swash plate position is extremely inefficient. High losses occur in the control valve, and often also in the swash plate bearings.

I am very pleased that finally some research is being performed in this direction. Yesterday, Mr. Jan Lux from IFAS gave an interesting presentation about this most urgent topic.

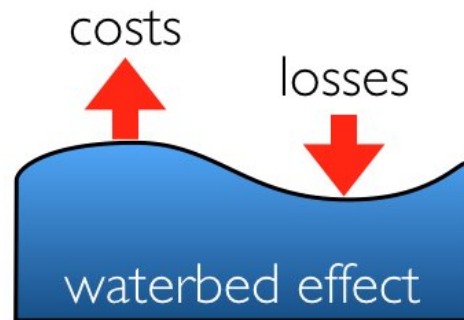


Mr. Lux also showed that there are possibilities to reduce these losses, for instance by means of electric actuators and modern electronic controls.

## the waterbed effect



# saturated development



old technology  
has reached its limit

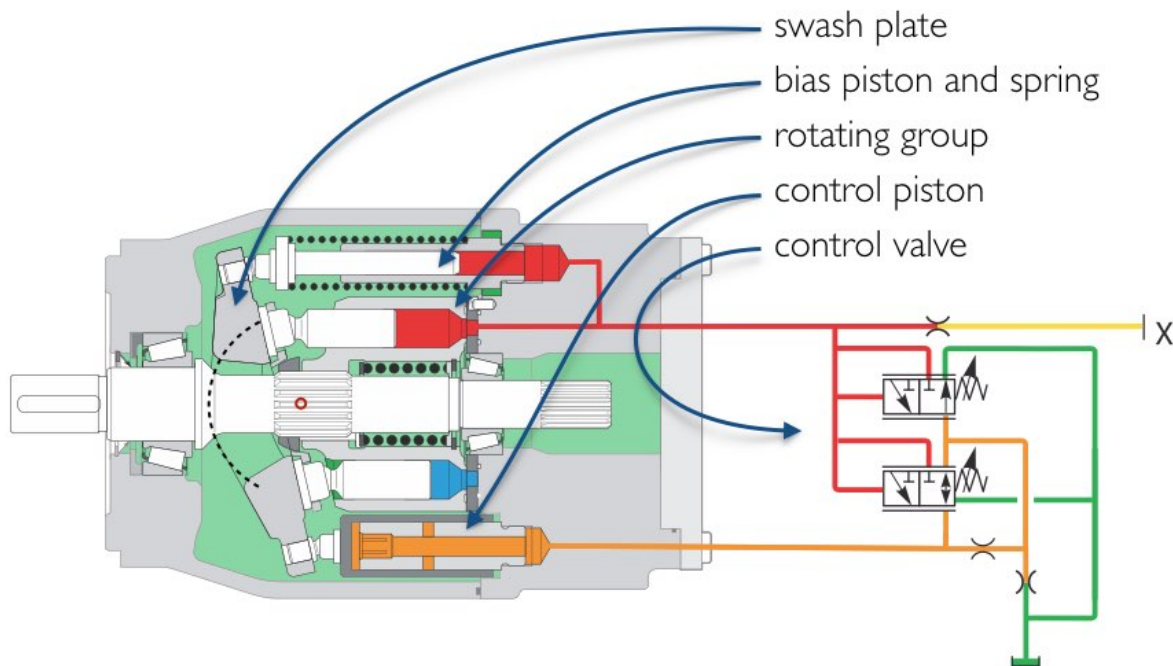
But, in the mature phase of a product cycle, these improvements are often offset by other detrimental effects: this is the so-called waterbed effect.

As an example: it is possible to reduce the losses of the displacement control, but the solution easily doubles or triples the costs of the total pump.

# what's wrong with current pump controls?

In order to have a better understanding of the problems of the pump control, we have to go to the basement, to the very foundation of the variable displacement swash plate pump.

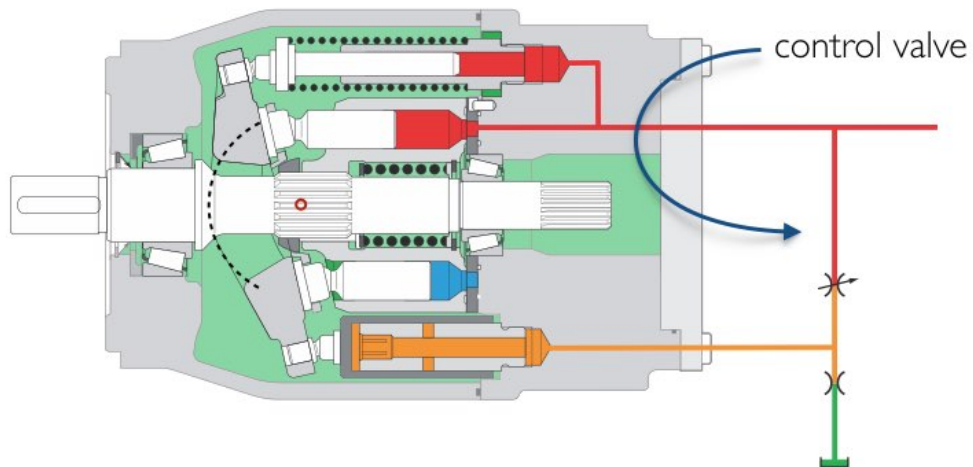
# displacement control



This cross section shows a –more or less– standard solution for open circuit pumps. The most important components are:

- the rotating group;
- the swash plate;
- the bias piston and spring;
- the control piston;
- and –of course– the control valve.

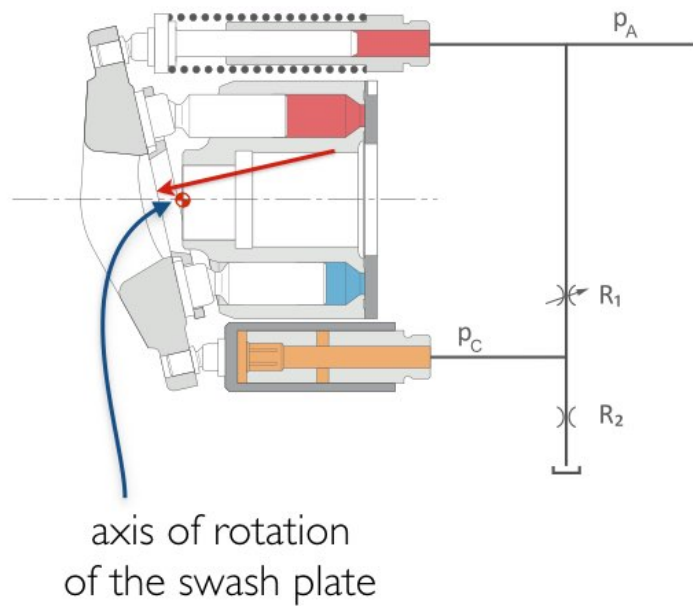
# displacement control



The control of a pump can be simplified by showing just two resistors in series.

Pump controls are essentially pressure dividers, similar to the inefficient resistive dividers in the old days of the electric industry.

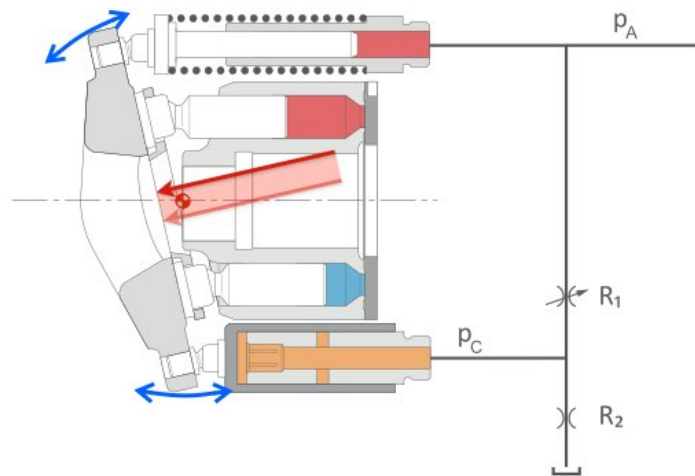
# lateral torque



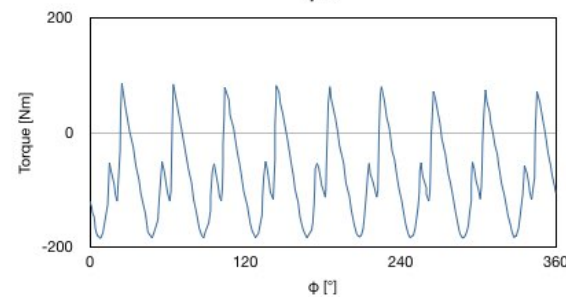
Now, let's have a detailed observation and better understanding of what actually happens inside the pump. The swash plate rotates around the indicated axis.

The red arrow represents the resultant force of all the pistons of the rotating group. This force creates a torque load on the swash plate.

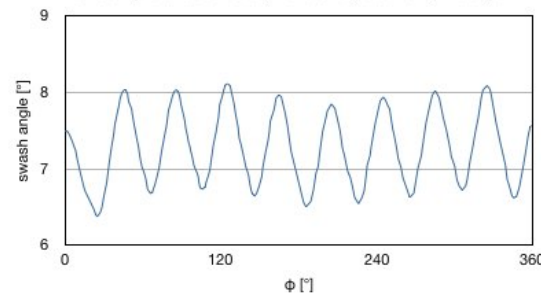
# swash plate oscillation



lateral swash plate torque, 40 cc/rev, 300 bar, 1450 rpm\*



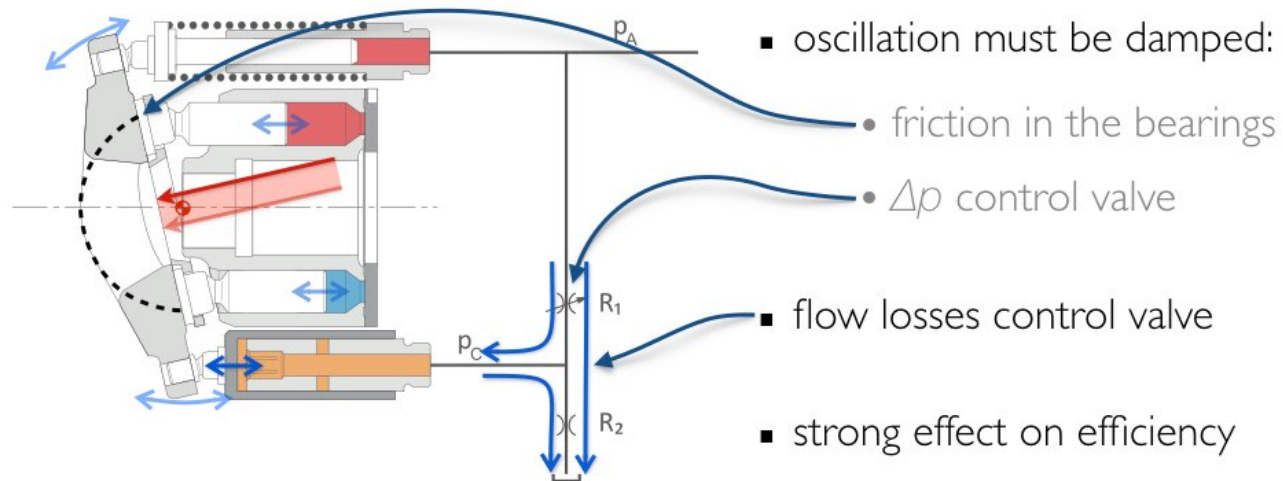
swash plate oscillation, 40 cc/rev, 300 bar, 1450 rpm\*



\*Bahr (2003) Vibration analysis of constant power regulated swash plate axial piston pumps

The force moves up and down, while the pump rotates. As a result, the torque load on the swash plate is not only very strong, but also very dynamic.

For a rather small 40 cc pump, being operated at 300 bar, this lateral torque can already become about 200 Nm. Driven by this varying torque load, the swash plate starts to oscillate. And, as you can see, this oscillation can be quite hefty.



For a correct operation of the pump, the oscillation amplitude needs to be minimized. There are various options:

- you can either create a lot of friction between the swash plate and the cradle bearing;
- or you can use the resistances of the flow control and let the control piston double as a shock absorber.

But, no matter what solution you choose, all of this is friction, and results in energy dissipation and efficiency reduction. And to make things even worse, in addition, there is a constant flow loss across the pump control.

Both effects, the damping and the flow losses, have a strong negative effect on the efficiency. In the best point, this loss is often as high as 5%. But for average operating conditions, these losses often amount to 10, 20% or even higher.

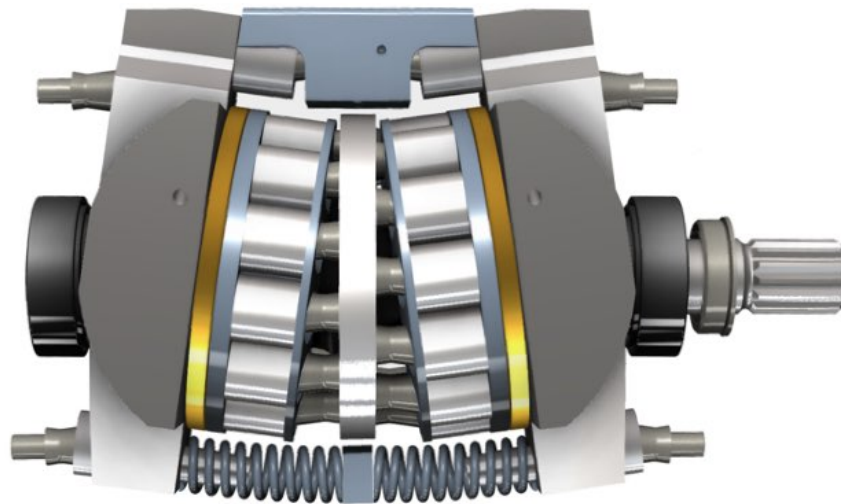


# the radical innovation

It is absolutely clear that this situation needs to be solved. We need a solution that reduces the losses of the control system, without deteriorating the dynamic behavior of the pump, or the durability of the swash plate bearings, and without causing an explosion of the costs of the pump.

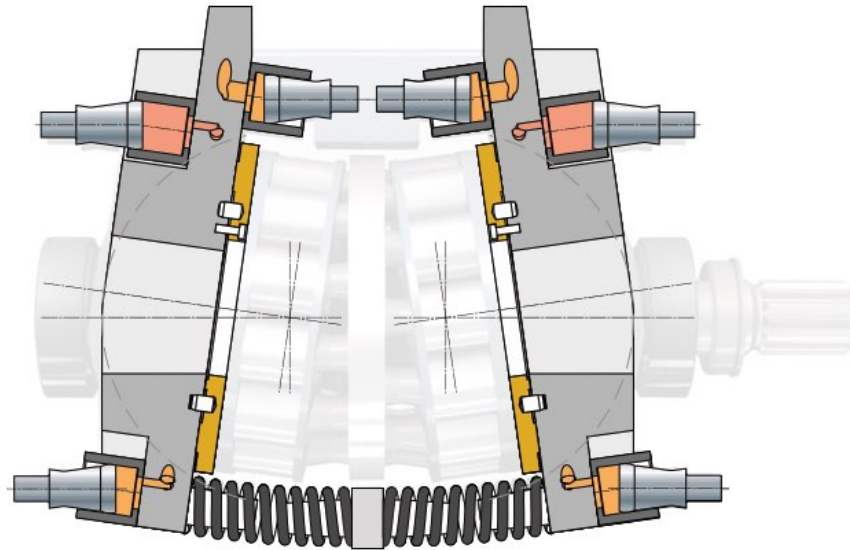
Whatever the solution will be, it will not be an incremental innovation. It will be a big step, a radical innovation.

# floating cup variable pump



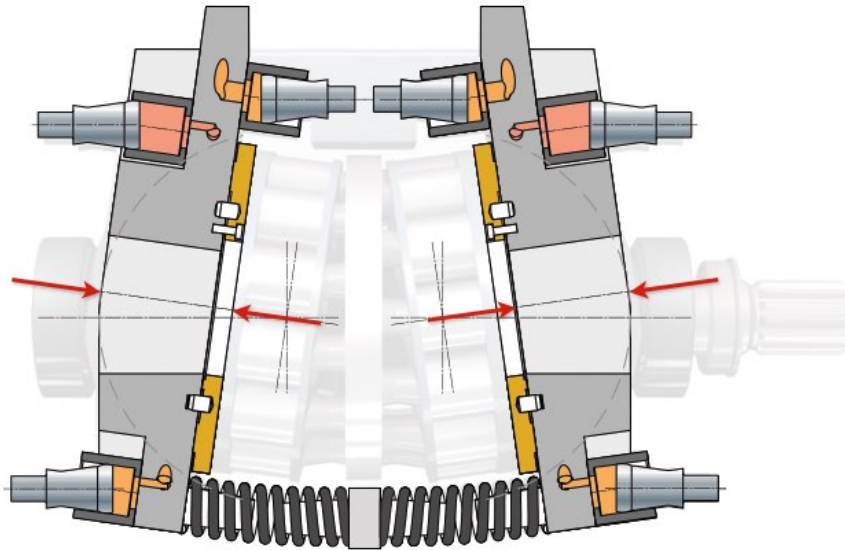
The variable displacement floating cup pump is certainly such a radical innovation.

# floating cup variable pump



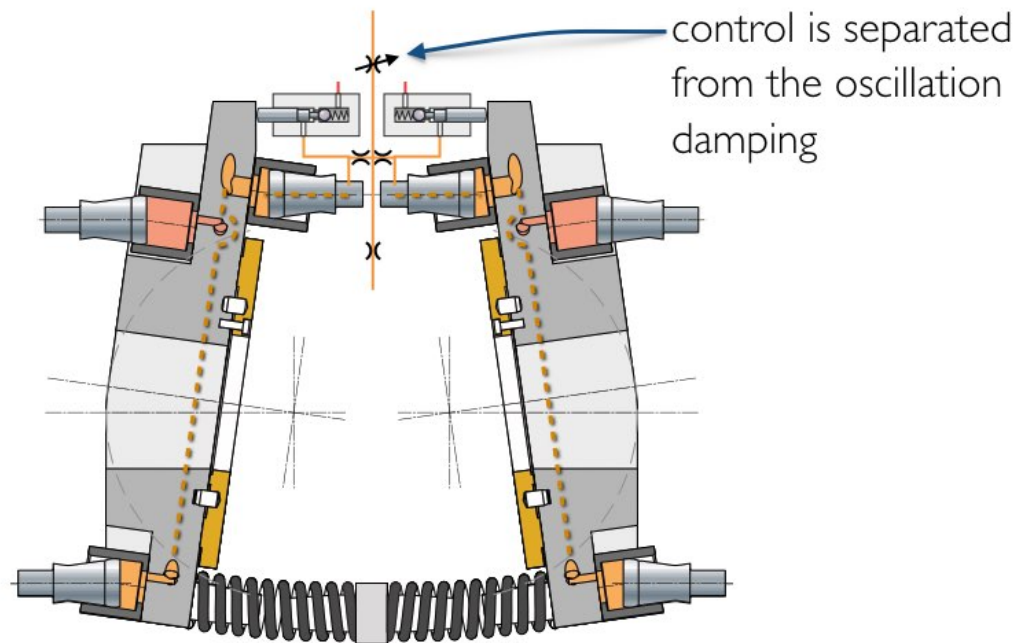
The floating cup principle features a double, more or less mirrored construction. It has two swash plates, both oscillating in counter phase.

# floating cup variable pump



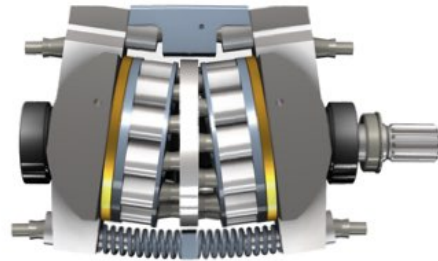
The swash plates have a close to 100% balance of the axial hydrostatic forces. As a result, the friction of the swash plate bearings is extremely small.

# floating cup variable pump



Furthermore, in the new design, the damping and control functions are separated. The pump control itself is optimized for the control function only, without needing to make a compromise for the oscillation damping.

Due to the minimal friction of the swash plate bearings, the actuators can be small. As a result, only small amounts of oil need to be supplied for changing the swash plate positions.



- strongly reduced bearing load
- small oscillation amplitudes
- fast and stable displacement control
- decimation of the losses of current pump controls

With the new design we achieved:

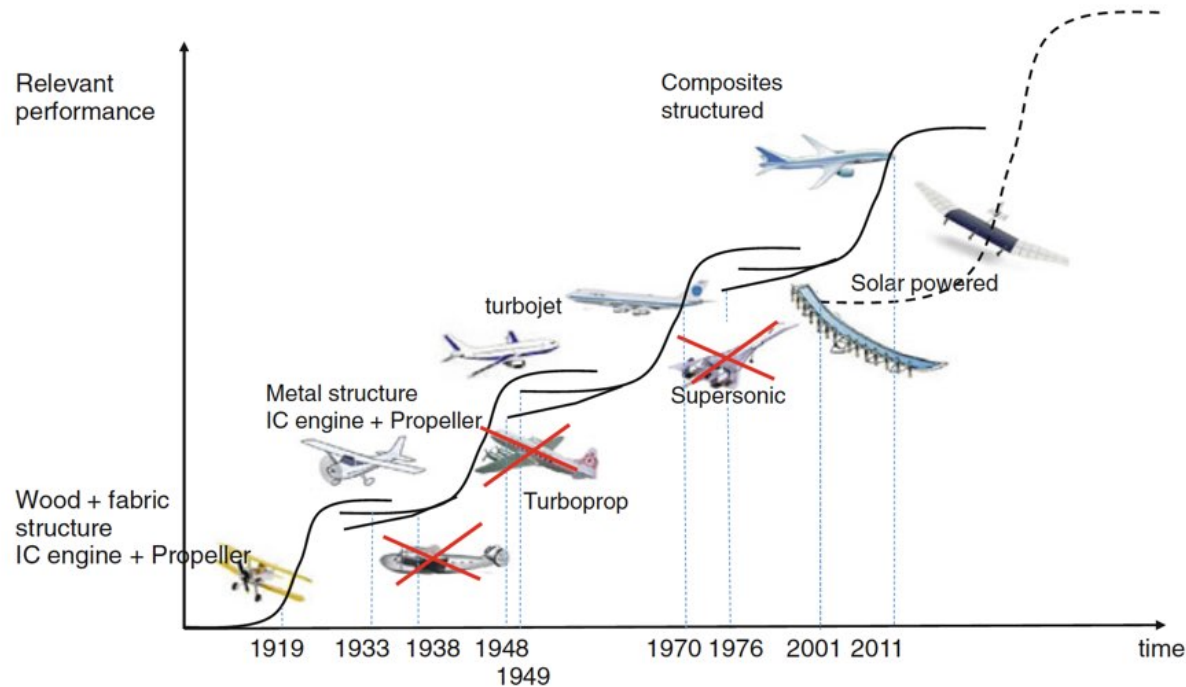
- a strong reduction of the bearing load;
- and small oscillation amplitudes.
- The new control is also fast and stable in the full range of operating conditions;
- But, most importantly, we managed to decimate the losses of current pump controls

In the previous years, I have had many discussions with the industry about innovation. Very often, I am told –or maybe I should say, I am warned– that the hydraulic industry is a very conservative industry, and that it is very difficult, if not impossible, to achieve any innovation at all.

what are we waiting for?

# civil aviation history

source: M. Cantamessa, F. Montagna, *Management of Innovation and Product Development*, Springer, 2016

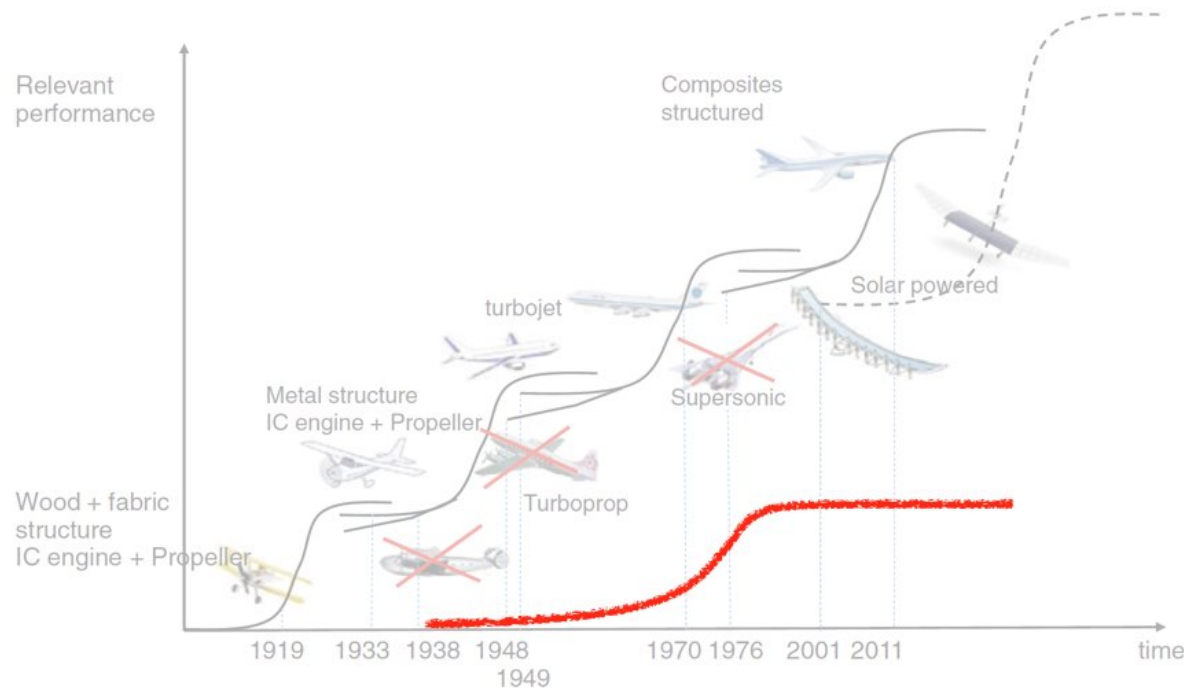


But, if there is any industry that should be conservative, than it is the civil aviation industry. Nevertheless, this industry constantly renews itself. In the past 100 years it has had at least 4 radical technology changes or revolutions.



# pumps and motors

The hydraulic pump and motor industry has had just one. And in the past 30 years nothing happened.





Let us have a last view at our metaphor, the Holland Island house. This house is one of the first victims of climate change.

Since the house was build, the sea level has risen by about 25 cm. Heavy storms have eroded what was left of the island.

To rephrase this in terms of the fluid power industry: our market has changed in the past century, and what used to be a perfect solution -the swash plate principle- is not fit for the new environment anymore.



This was the Holland Island house shortly after the previous photo. In terms of the pump industry: this could be your situation in a few years. Do something about it!



What... are you waiting for?