Keynote speech

2016 Fluid Power Research and Innovation Conference (FPIRC)
ASME 2016 Dynamic Systems and Control Conference (DSCC)

October 12, 2016, Minneapolis, Minnesota, USA

Peter Achten, INNAS, The Netherlands (www.innas.com)

Music: OLD, NEW & BLUE
Channel Classics
Holland Baroque meets Eric Vloeimans
nr. 3: Bach: Choral Ertöt Uns Durch Dein Güte

Well, good morning everybody.
Are you still a bit sleepy?
Let me try to wake you up with some music.
Baroque music. Written by Johann Sebastian Bach.

300 Years ago, this was modern music. Now let me ask you, what you are listening to?

Who knows what this is? Let me help you.
This…this is the fluid power industry. What you hear is it origin, at the beginning of last century. Like an old squeezebox it plays its tune. It started about 100 years ago in Great Britain, with men like George Dowty and Joseph Bamford, Maurice Ingoldby, Henry Selby Hele-Shaw and Francis Hector Clergue.
In the 20th century it has been growing, slow, but steady.

These are Vickers, Sauer, Eaton, Danfoss, Parker Hannifin, Bosch Rexroth and all the other players in the fluid power orchestra, all playing the same tune. Becoming bigger and more important as the time goes by.

What was this? That, ladies and gentleman was innovation

You can hear the establishment think: this is completely wrong. That is the not the proper way to play our tune.

There it is again. 'How odd, how dissonant, how disruptive' the incumbents cry out. We have to stop this guy playing on his trumpet. Otherwise we can't continue to play as we are used to. The audience, the market, for sure doesn't want this.

But the new music, the innovation, doesn't stop. It adapts and improves itself until it finds the right tune. It improvises. It has to. Innovations are never perfect at the beginning. They start as an idea, just an idea. And then they have to be improved, by learning. Learning from experiments, learning from failures, learning from feedback from the market, from experts and from conferences like these, and even learning from competitors.

And then, almost when you think it is not going to make it, something remarkably happens. Listen! Listen very carefully. Can you hear it?: the trumpet player is not alone anymore.

Others, from the industry are joining him. You can still hear it –the old industry– the basis is still there. But it has also completely changed, almost beyond recognition. This is no longer a squeeze box. This is jazz. The old music has become modern again.

At this point, the industry has reinvented itself. It had to, simply because the world around it didn't stop in the baroque era, but moved on and changed. The environment, the market, the demands from their customers changed. And the industry had no alternative: it had to change as well. But crucial in this process are the innovations. Innovations, created by skilled engineers, have been, and always will be the basis for this change.

The Via Negativa

INNAS

Peter Achten
Minneapolis, October 12, 2016

Ladies and gentleman.
This is very special for me. I have never addressed two conferences at the same time. I have also never started a presentation with music.

Welcome to you, all you engineers from the fluid power world. Where are you? For you, this will be an easy game: you are not only experts in fluid power, but you also know about dynamic systems and controls. After all, most hydraulic systems are dynamic and need to be controlled. So you know all about Bode plots, Nyquist diagrams and Laplace transformations, don't you?

And also a kind and warm welcome to all of you, participating in the Dynamic Systems and Controls Conference. Please raise your hands. There you are! Of course, I don't need to explain you anything about Lyapunov stability, do I? But you might need some help with fluid power. Don’t worry. I’ll try to sort out and explain things for you.

The Via Negativa

INNAS

Peter Achten
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Today, I will tell you a story. A story about beautiful art and some wise man. A story about a labyrinth, …in which you can get lost. And a story about the secret of successful creativity.

The power to create is one of the most precious gifts of mankind. It is the ability to find new ways and new solutions, often for problems, that we –ourselves– created. In order to find new solutions, creativity needs to be combined with skills, knowledge and of course talent. The combination is called craftsmanship. In the end, the quest for a designer is not to find just a random solution, which you might do with just creativity, but to find the right solution.

But how? How do you find the right solution, the good design, amidst thousands of wrong ideas?
Well, there is a methodology. It is called:

…the ‘via negativa’. It could be translated as, the ‘negative way’, but I prefer to call it ‘the method of avoiding problems’.

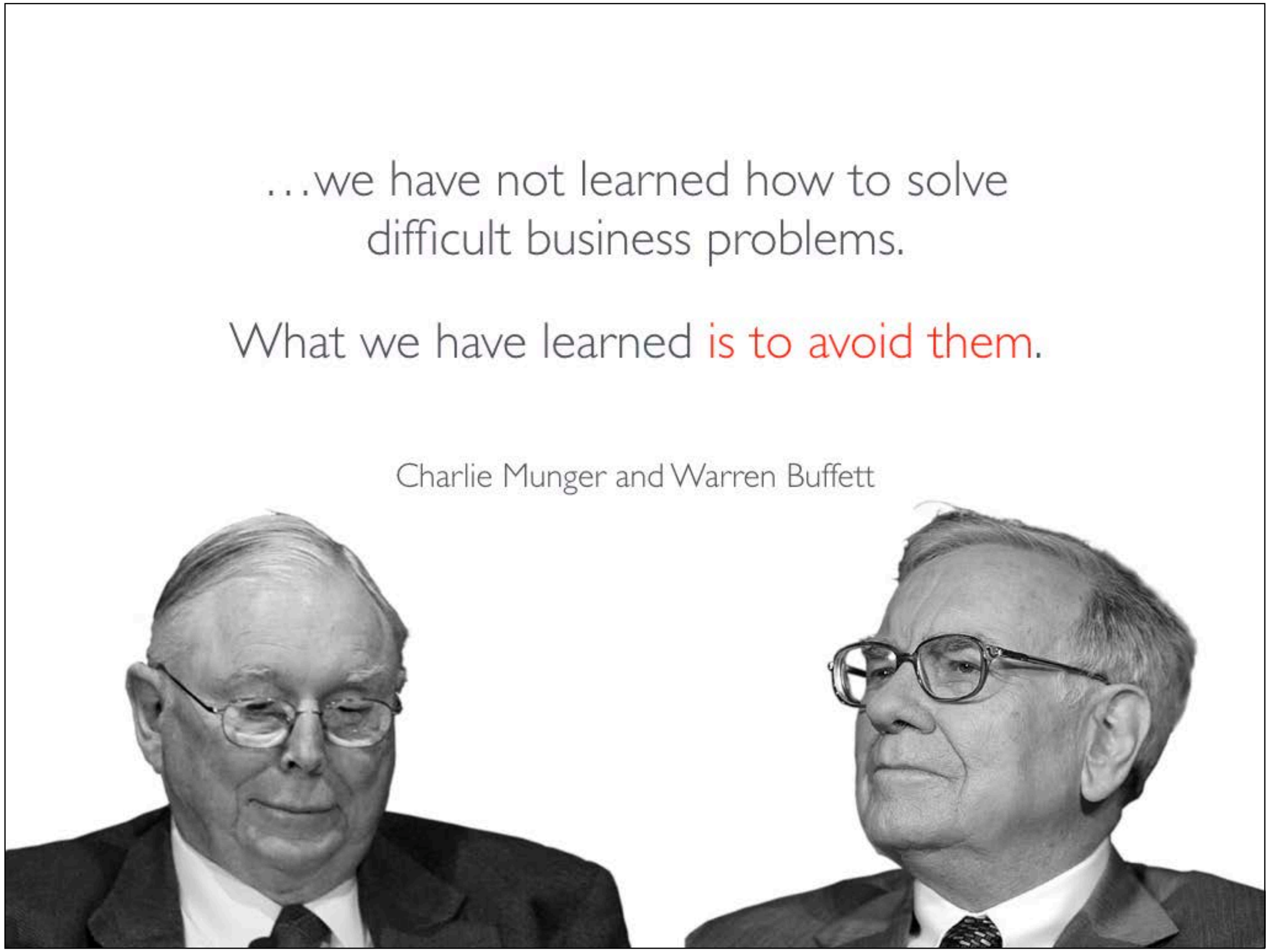
Let me give you some general examples of the ‘via negativa’ from a few wise men.

The aim of the wise is not to secure pleasure,
but to avoid pain

Aristotle

According to Aristotle, the aim of your life should not be to secure pleasure…
…but to avoid pain.

The ‘via negativa’: simply avoid pain and misfortune, and you will have a good life.

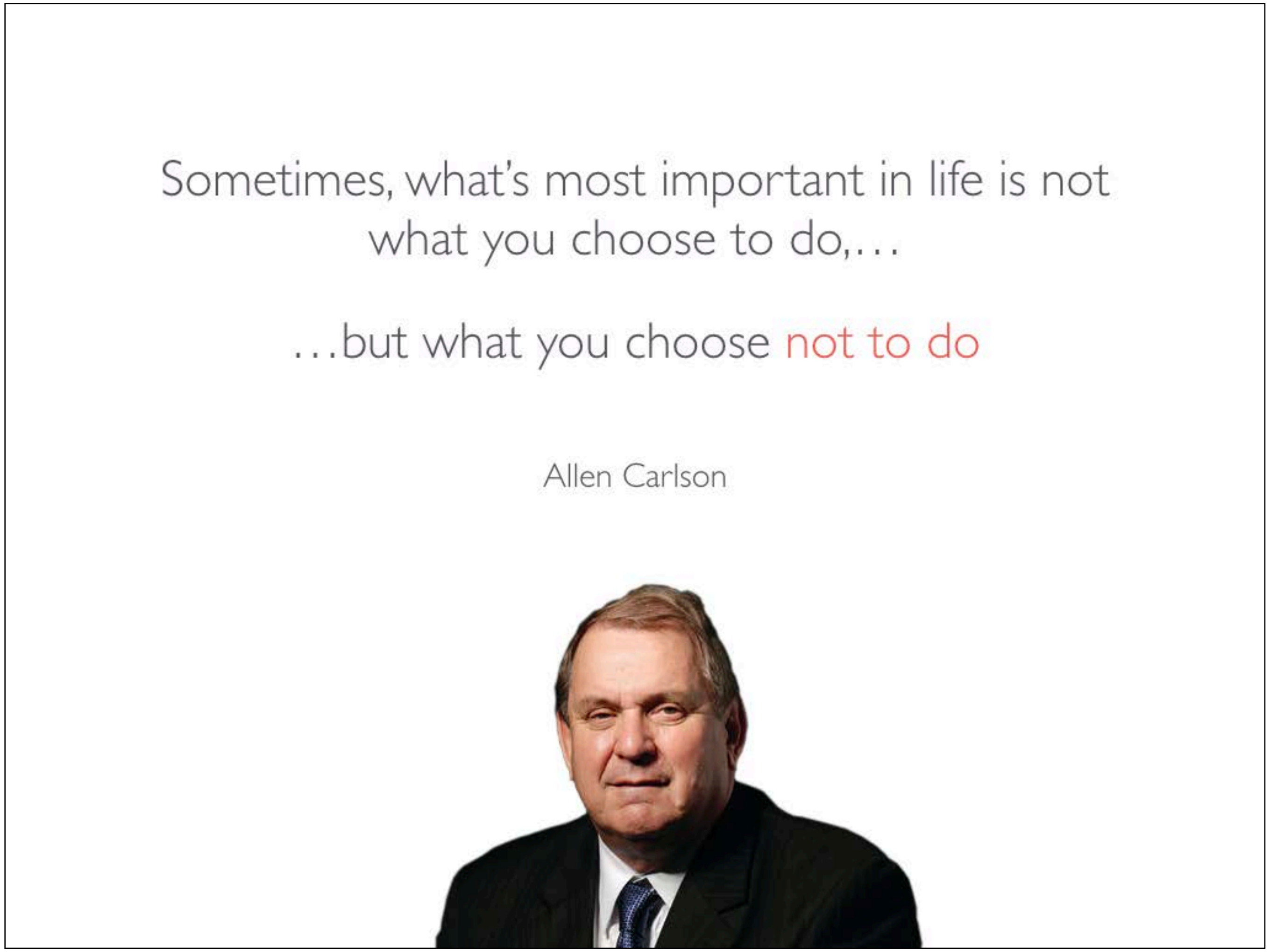


Another example was given by two of the most successful businessmen, Charlie Munger and Warren Buffett.

"…we have not learned how to solve difficult business problems" they once said…

…"What we have learned is to avoid them".

The 'via negativa'.



And finally, a quote from a captain of the hydraulic industry, Allen Carlson, the former CEO of Sun Hydraulics:

"Sometimes, what's most important in life is not what you choose to do,"…

…"but what you choose not to do".

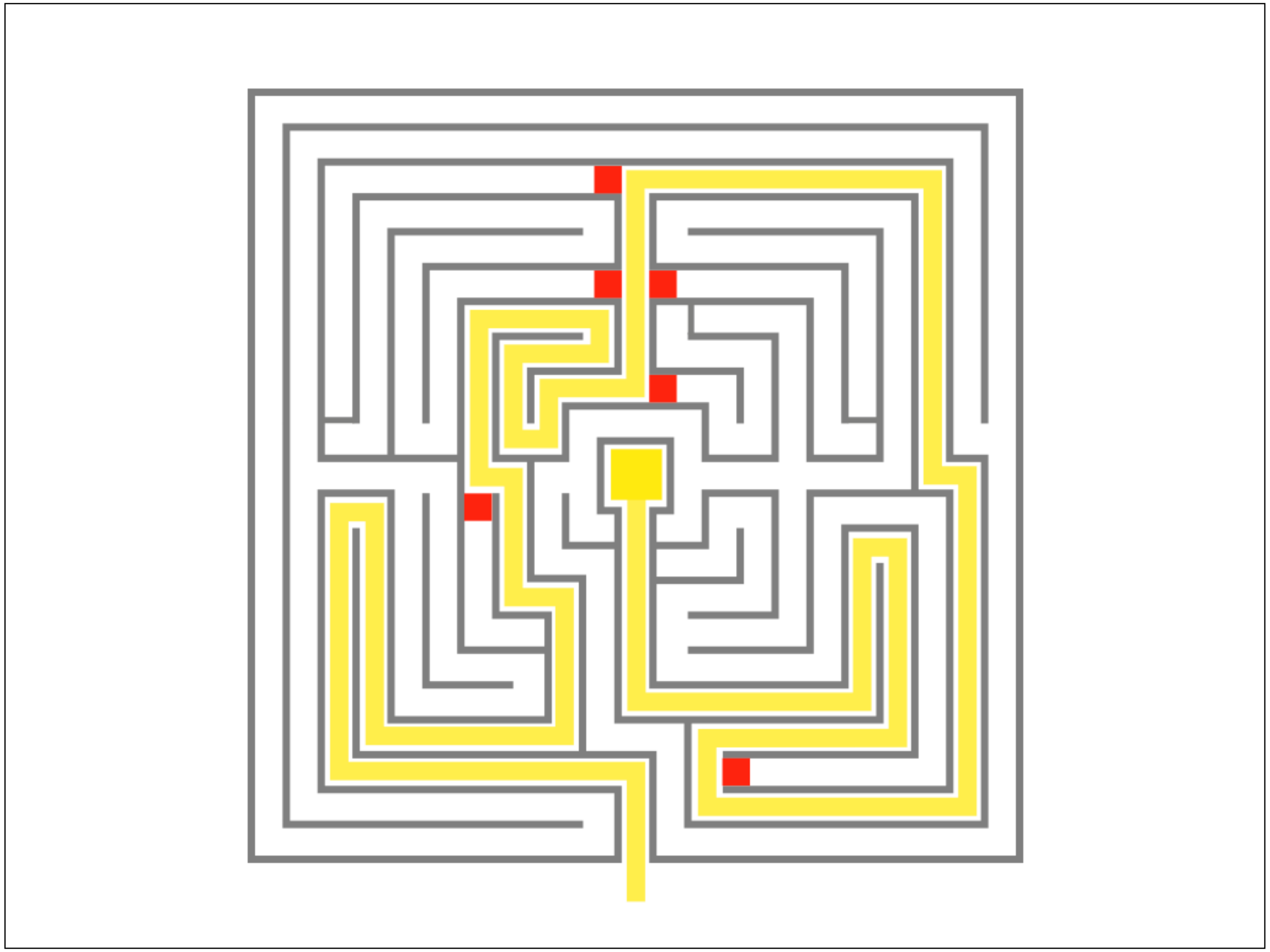
Via Negativa

Designing by avoiding problems

The ‘via negativa’. Design, simply by means of avoiding problems.

The idea behind it is, that it is impossible, or –at least– very hard, to find something, which doesn’t exist yet.

But, we do know, or at least should know, the problems and disadvantages of current designs.



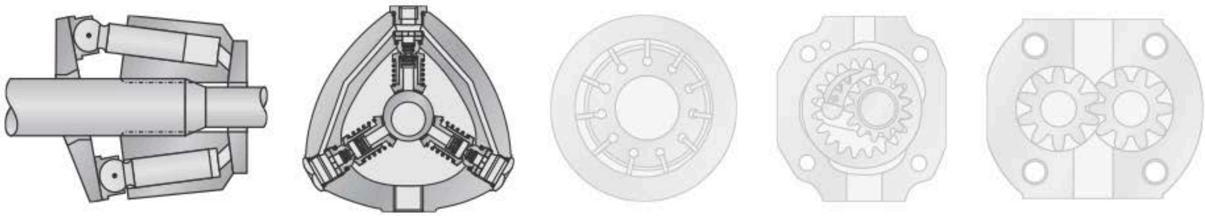
The philosophy of the ‘via negativa’ can be best explained by means of a maze.

If you know which turns to avoid, you will be directed automatically to the right solution:

The new and better solution will present itself.

example: pumps

- heavy duty: ≥ 350 bar
- constant & variable displacement
- efficiency



Let me show you how this works, by taking current hydrostatic pumps as an example. heavy duty pumps, to be precise…

… both constant and variable displacement.

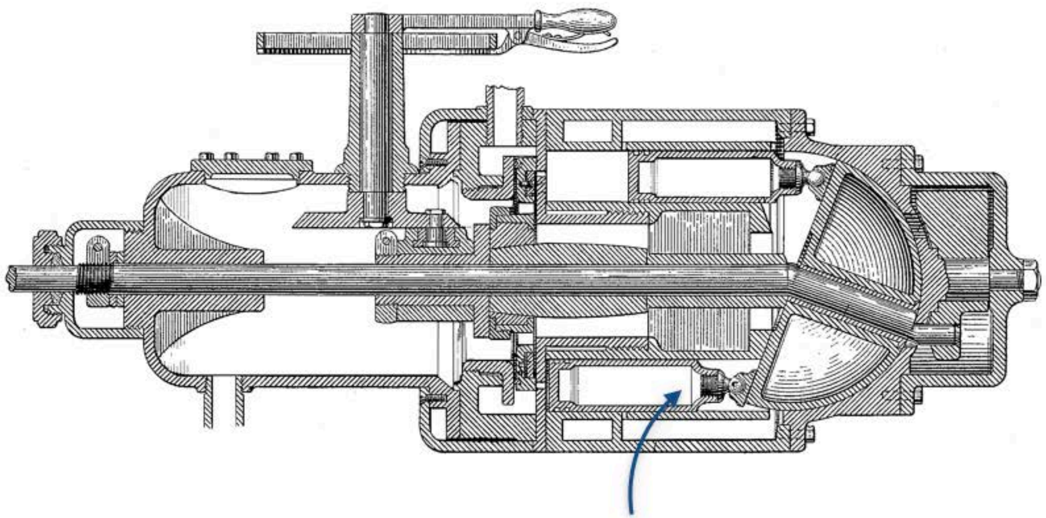
Today, I will only talk about piston pump principles, and about the efficiency as a design parameter.

Our quest can therefore be defined as a search for a new, efficient, hydrostatic principle

the swash plate principle

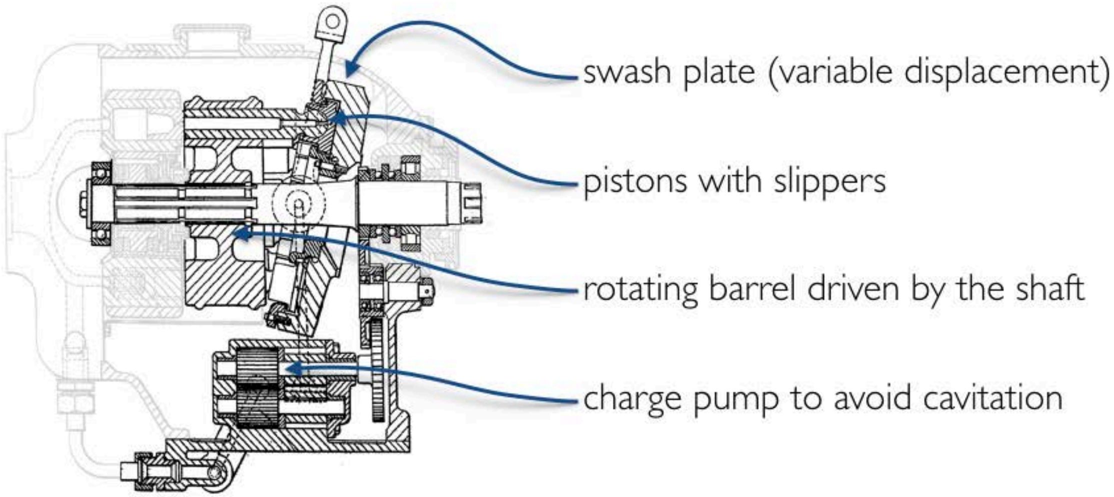
But, before discussing this in more detail, let me take a step back with you, and have a look at the evolution and lifecycle of the swash plate principle.

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)

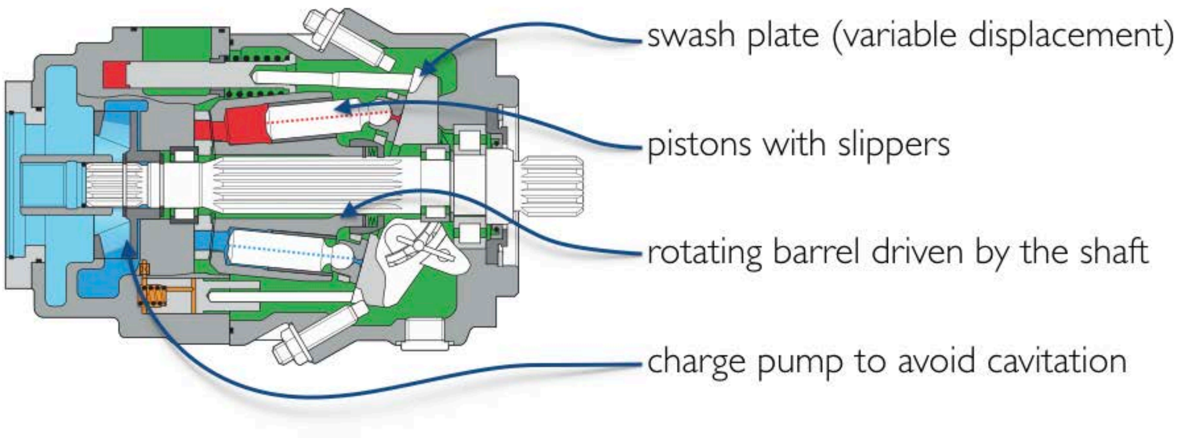


The principle was not very effective as a steam engine, but was later on successfully implemented in many designs of hydrostatic pumps and motors.

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

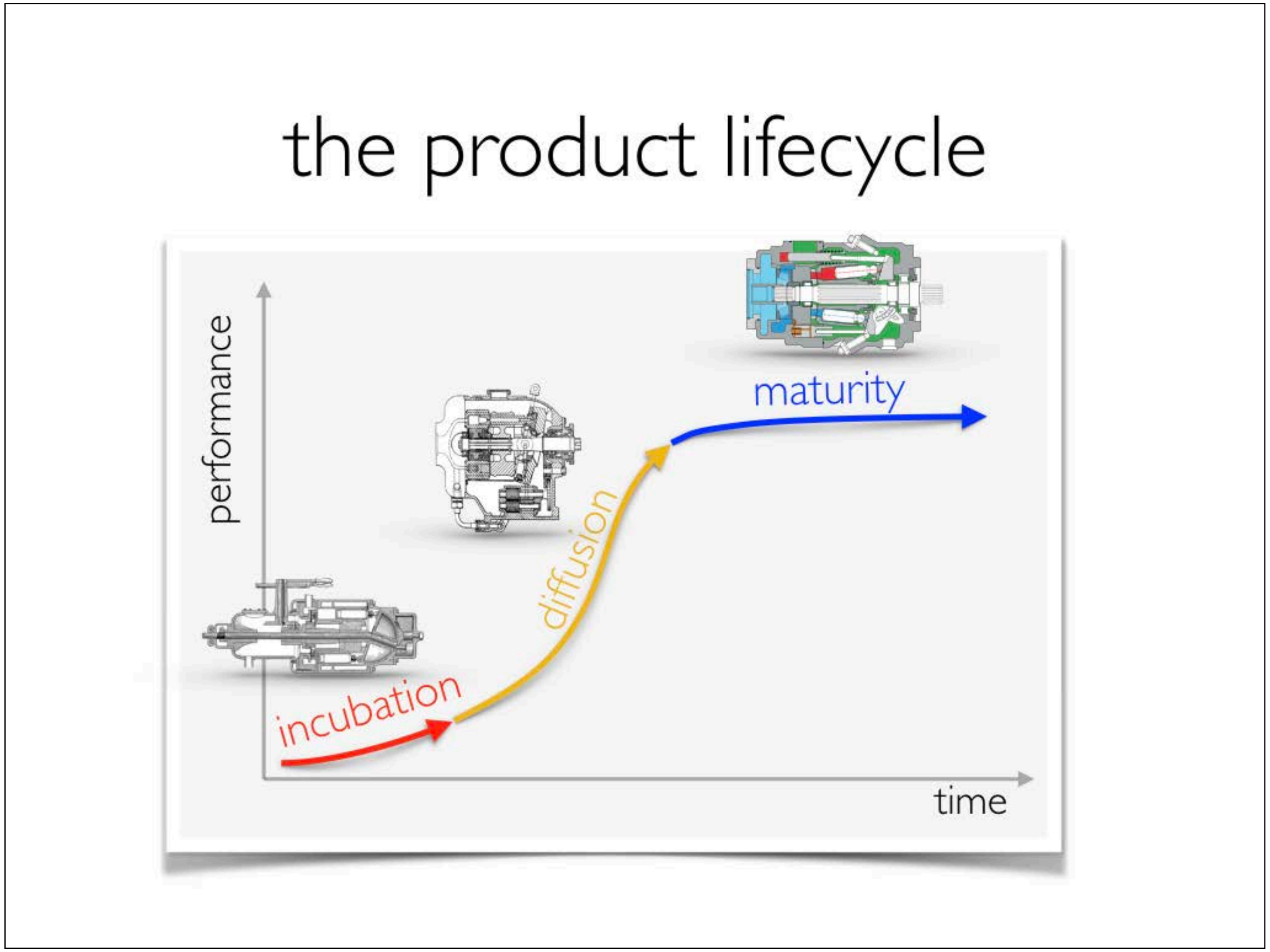
- the swash plate, which can be rotated to change the displacement;
- the pistons and slippers;
- the rotating barrel, which is driven by the shaft;
- and even a charge pump to avoid cavitation.

Bosch Rexroth (2016)



The same elements can be found in todays in-line axial piston pumps:

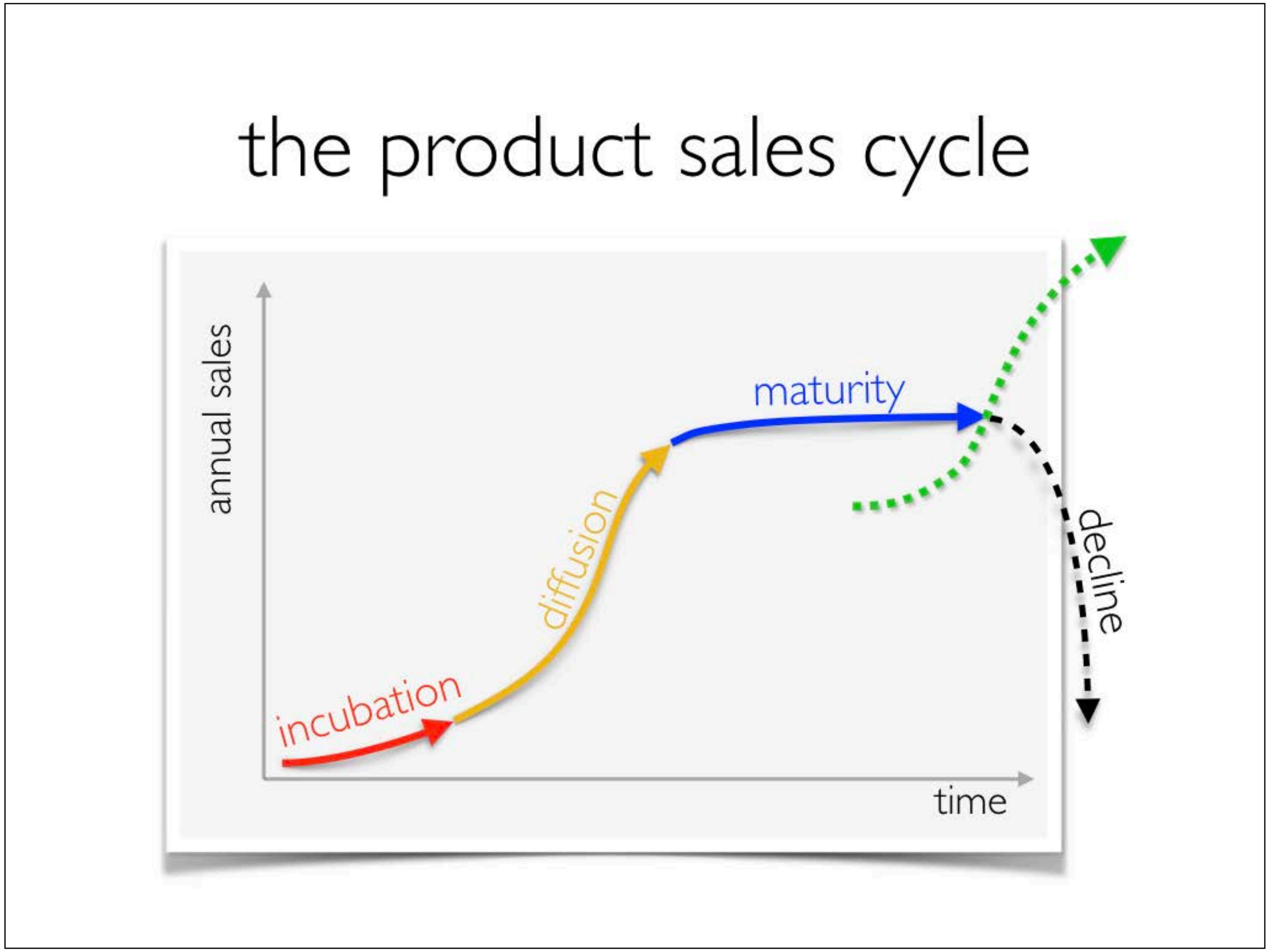
- a swash plate;
- a group of pistons, each having its own slipper;
- a rotating cylinder barrel, driven by the shaft;
- and –if needed– a charge pump.



The 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.



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

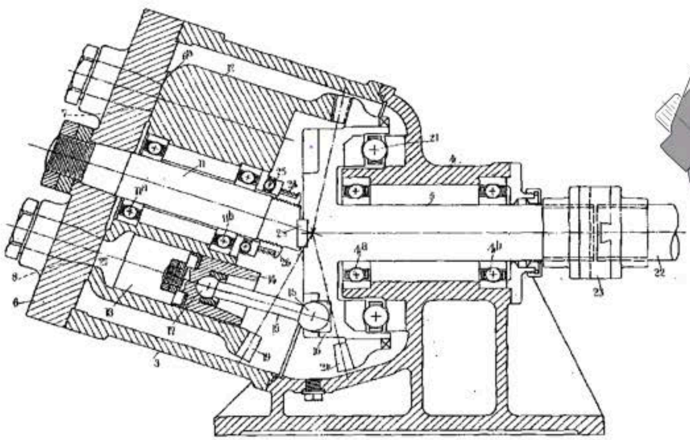
The diagram looks the same as the previous performance diagram. But, there is an important difference: this diagram has a fourth phase: the decline.

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

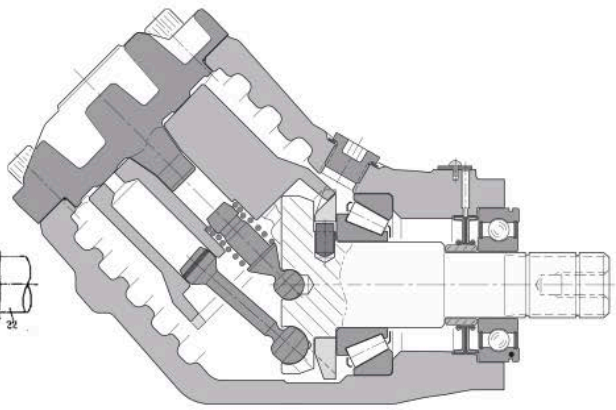
what has happened in the past decades?

So, where are we now, with current pumps and motors? Is it true, what I just showed to you, that we have reached the maturity phase, the phase with limited progress and almost no economic growth? What has happened in the past decades? What progress has been really achieved?

Bent axis



Clergue (1909)

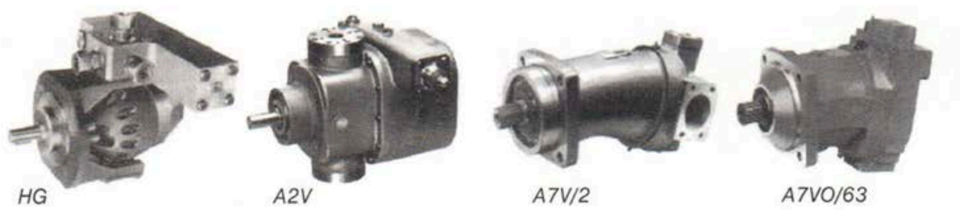


Parker F1 (2015)

This time we will look at another axial piston principle: the bent axis.

In the year 1909, Francis Hector Clergue, from the city of Westminster in Great Britain, received a patent on a bent axis pump or motor.

The similarity with the modern bent axis F1 from Parker is striking.

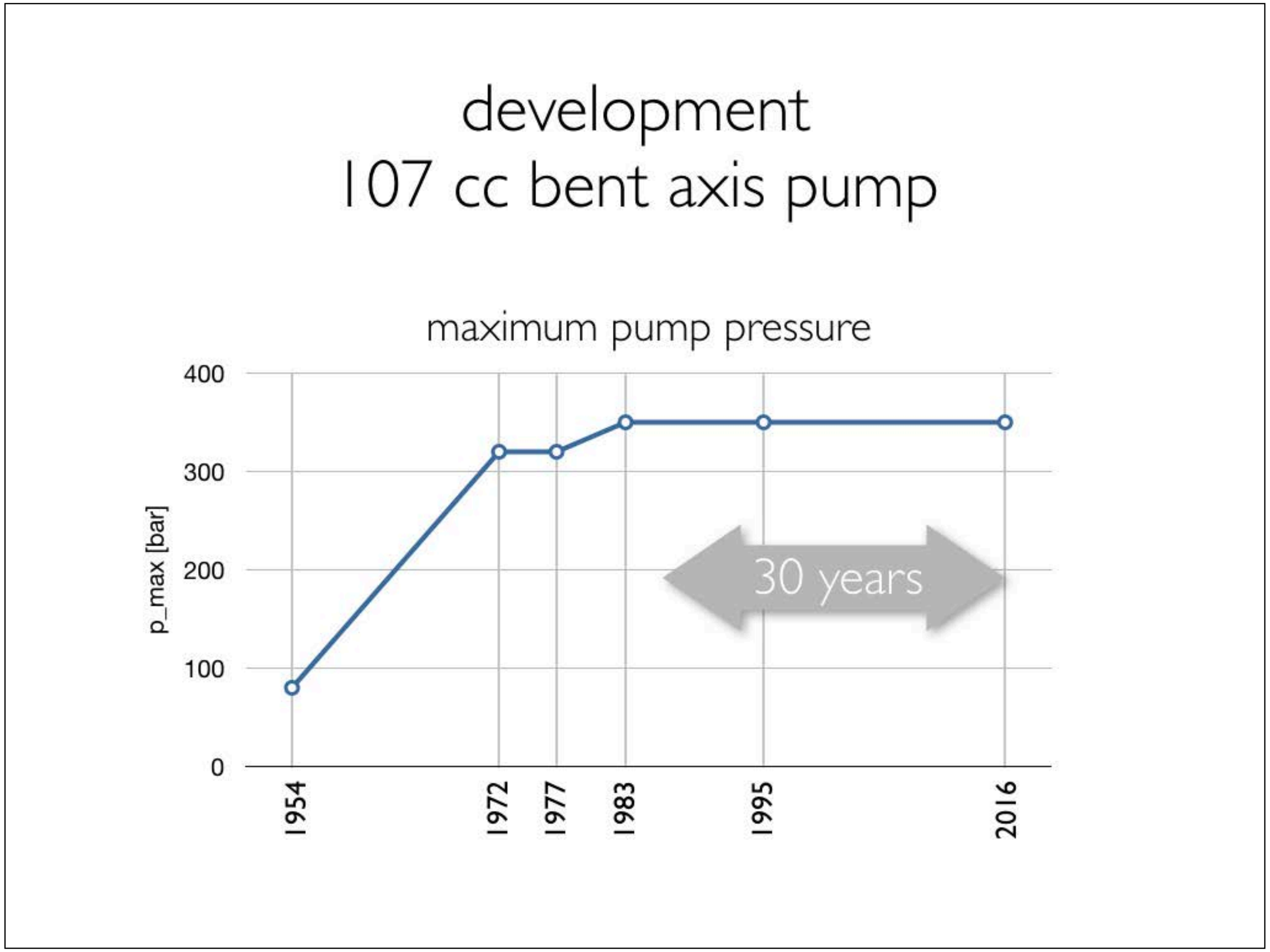


Year	1954	1972	1977	1983	1995	2016
maximum displacement [cc/rev]	107	107	107	107	107	107
maximum pressure [bar]	250	400	400	400	400	400
rated pressure [bar]	80	320	320	350	350	350
maximum rotational speed [rpm]	1450	2000	2000	2000	2150	2150
flow at maximum speed [L/min]	150	208	208	208	223	223
Power [kW]	20	114	114	125	134	134
Weight [kg]	110	100	53	49	49	49
power density [kW/kg]	0,2	1,14	2,15	2,55	2,73	2,73

In 1997, the German fluid power journal O+P showed the progress of the hydraulic industry in the second half of last century. This was one of the tables the journal presented. It shows 40 years of development of bent axis pumps.

I have taken the liberty to add another column, showing the present values.

A comparison of the values of 1995 and 2016 reveals something interesting: the two columns are identical. Nothing has changed!

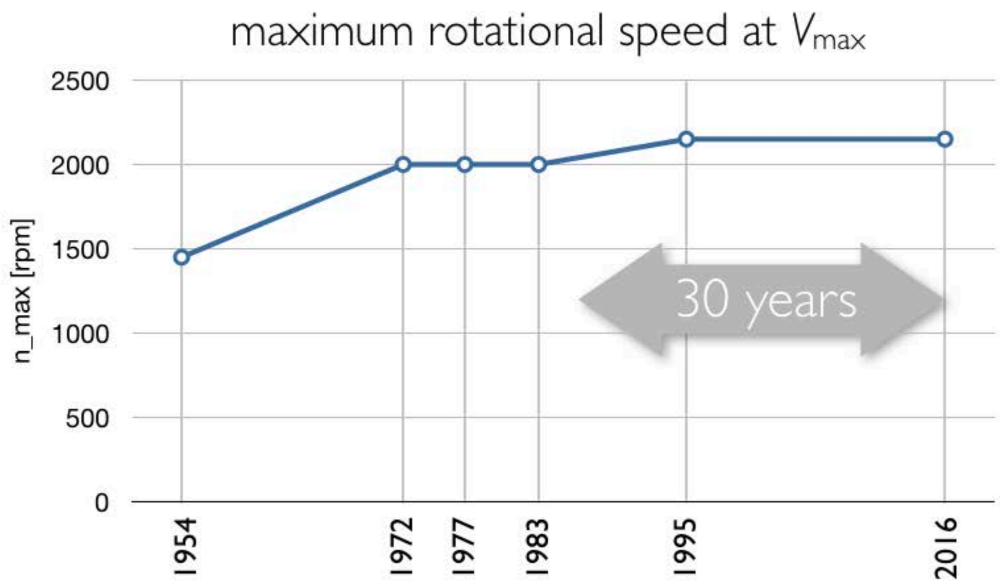


These are the same data, but now displayed in a diagram. The graph shows the maximum pump pressure as it has developed over the years. Between 1954 and 1972 there is an enormous progress. After that, the improvements become incremental.

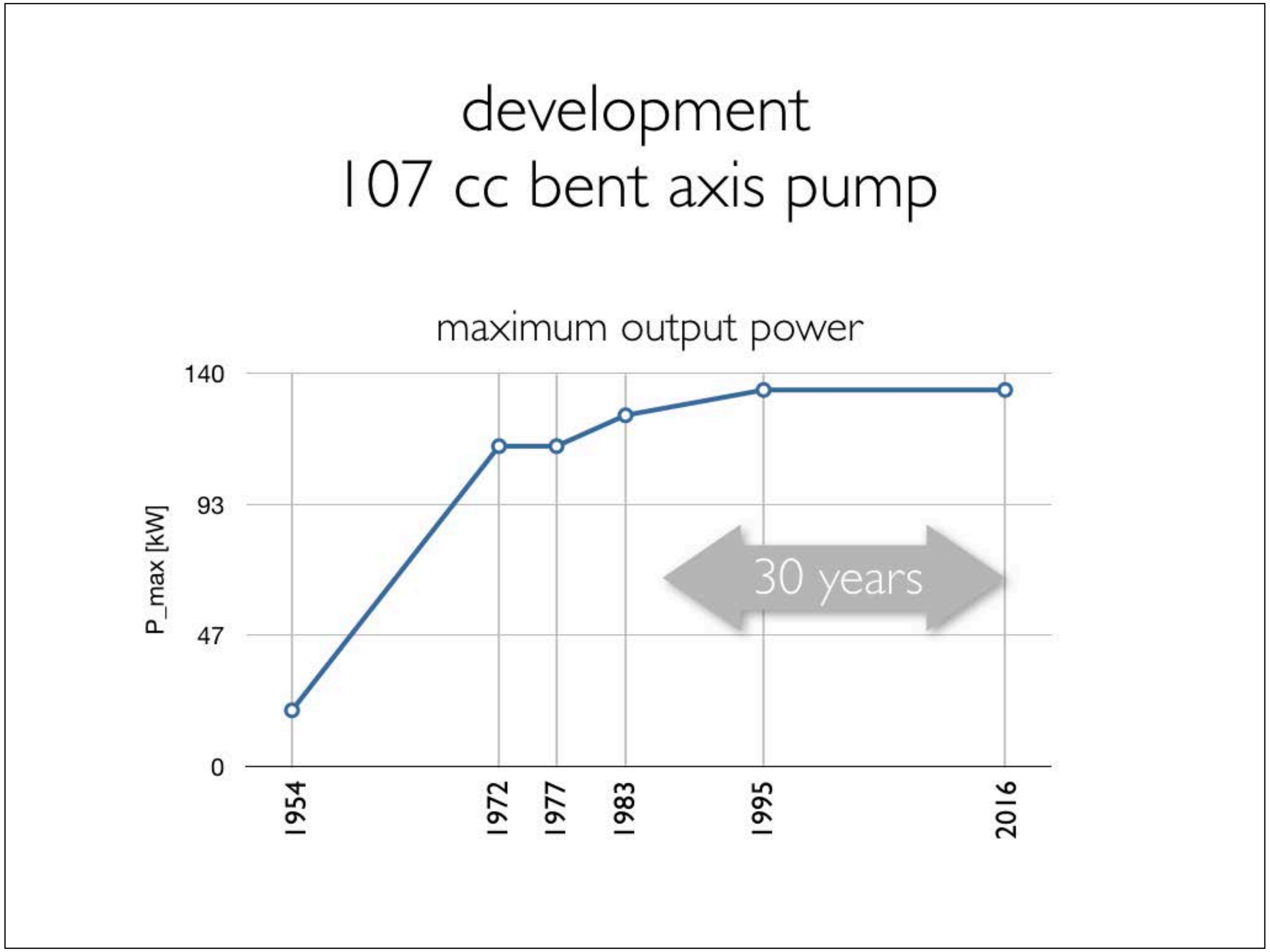
I started my professional career in the fluid power industry more than thirty years ago. In this period nothing has changed. And before you ask: No,…no, no,… I don't feel responsible for this.

The same pattern can be seen for the other parameters:

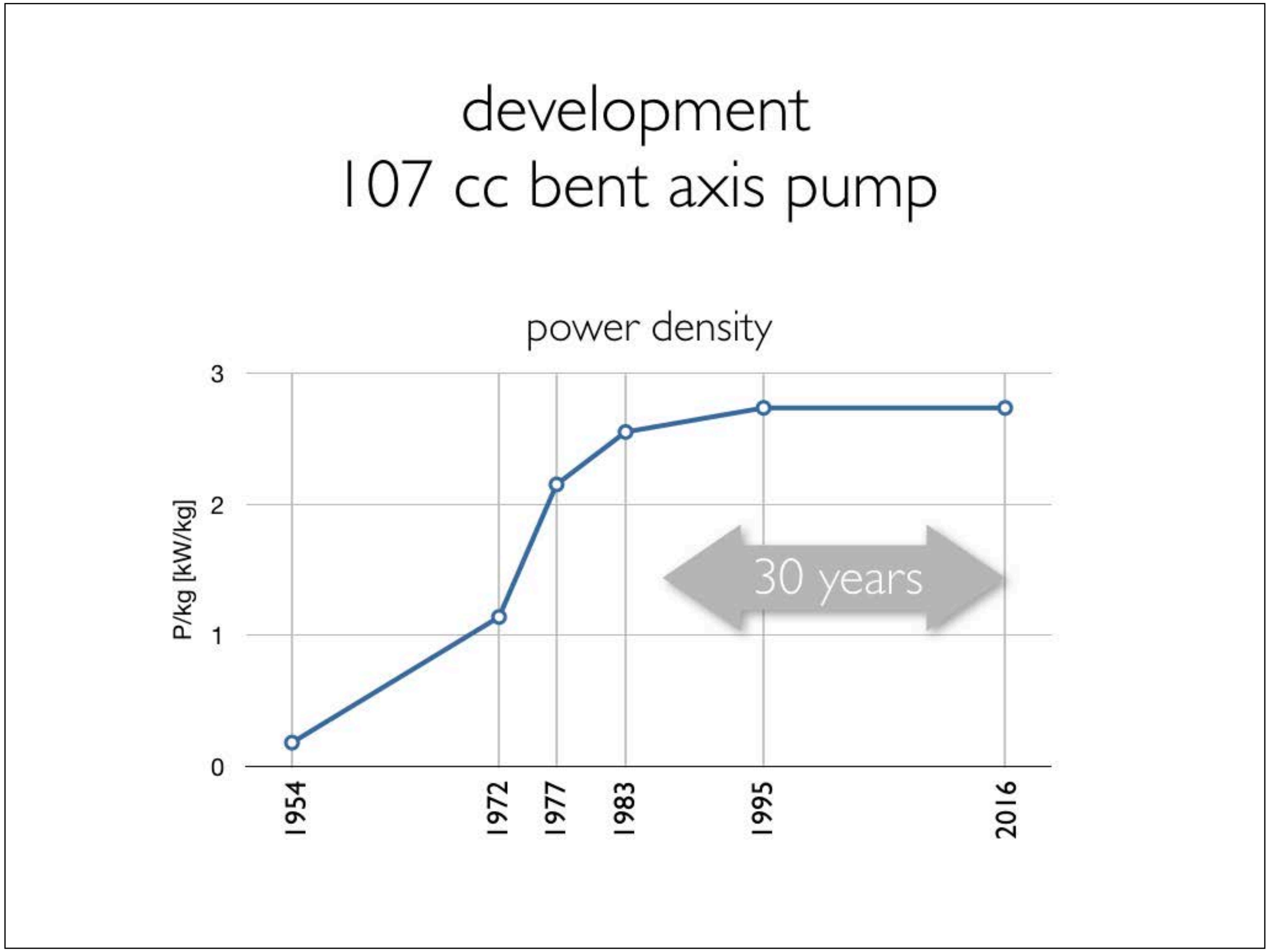
development
107 cc bent axis pump



The maximum rotational speed;



The maximum output power;



And the power density.

what have we learned?

This,… is no progress; this is standstill.

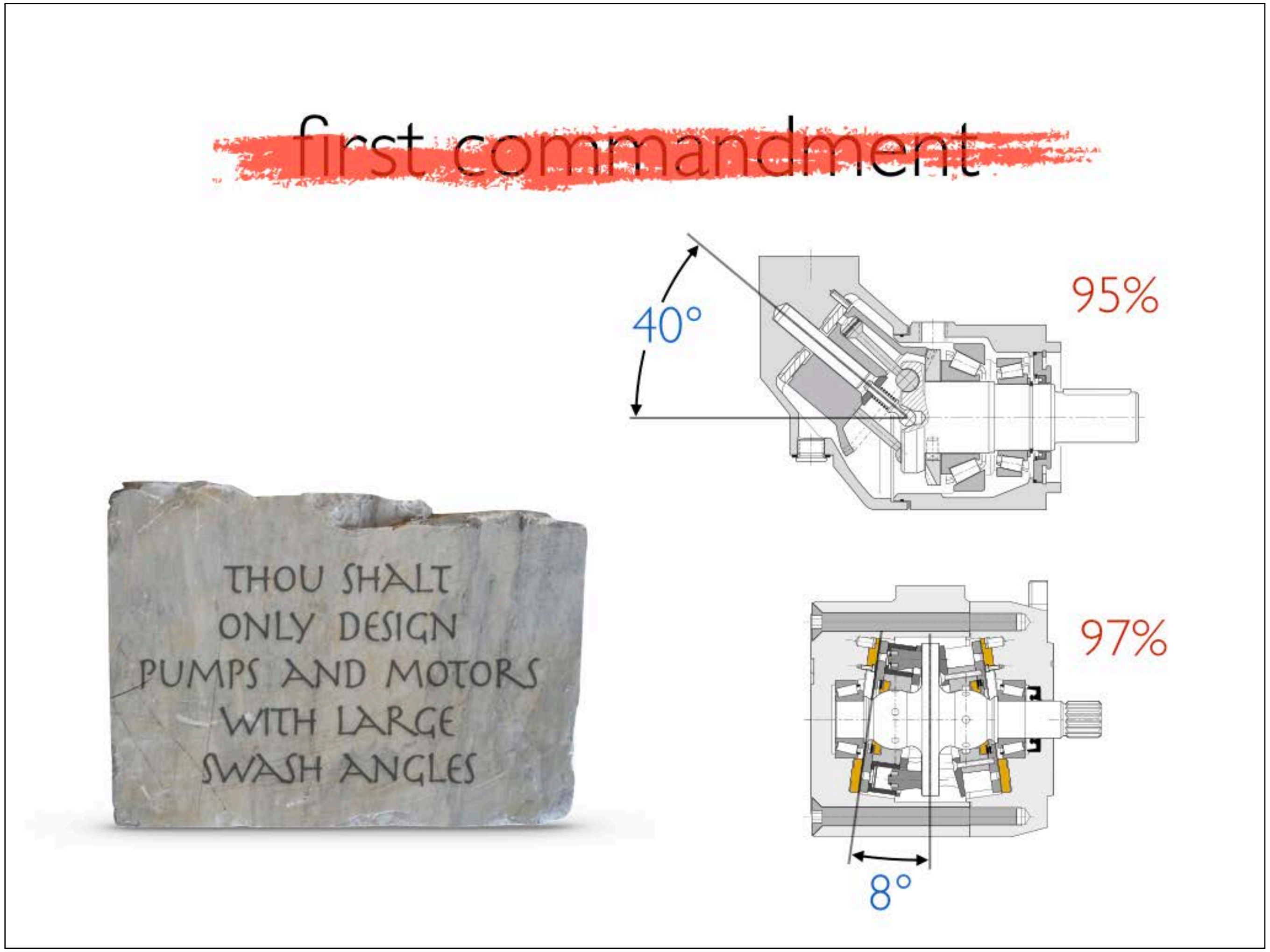
But, how about the efficiency?

Remember, our quest is for an efficient pump.

first commandment

Let me start with an often heard basic rule for the design of efficient hydrostatic machines:

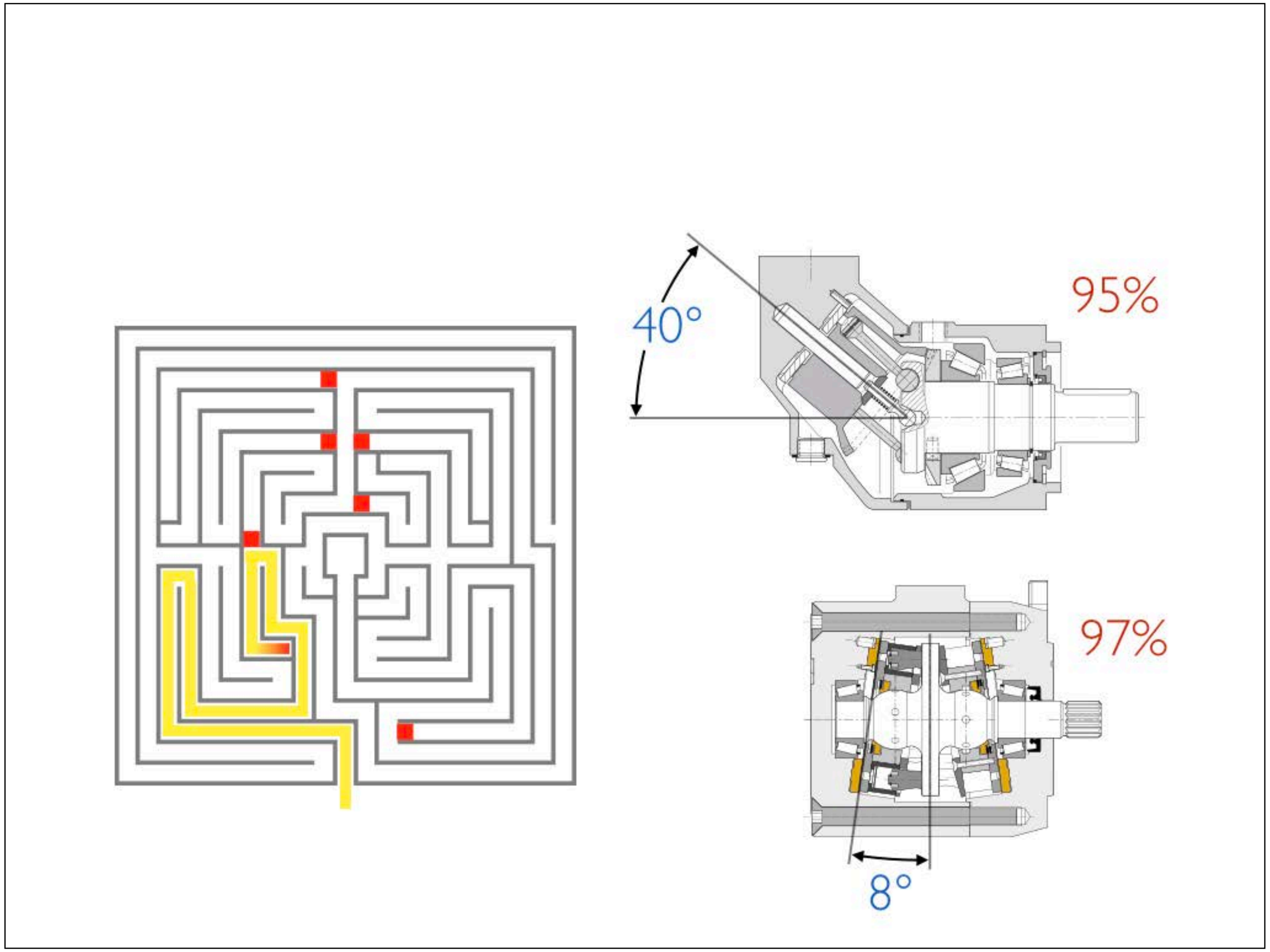
"Thou shalt only design pumps and motors with large swash angles!" For some, this is nothing less than a commandment, carved in stone."



Only machines with a large tilt angle, they argue, like this F12 from Parker, can achieve a high efficiency.

However, our company and many others, have proven that this guideline is utterly wrong. This new pump achieves efficiencies of 97%, whereas the tilt angle of the barrel is only 8°.

If we want to succeed in our search for improvements, it is important to avoid these misconceptions.



Otherwise we end up at a dead end in the labyrinth.

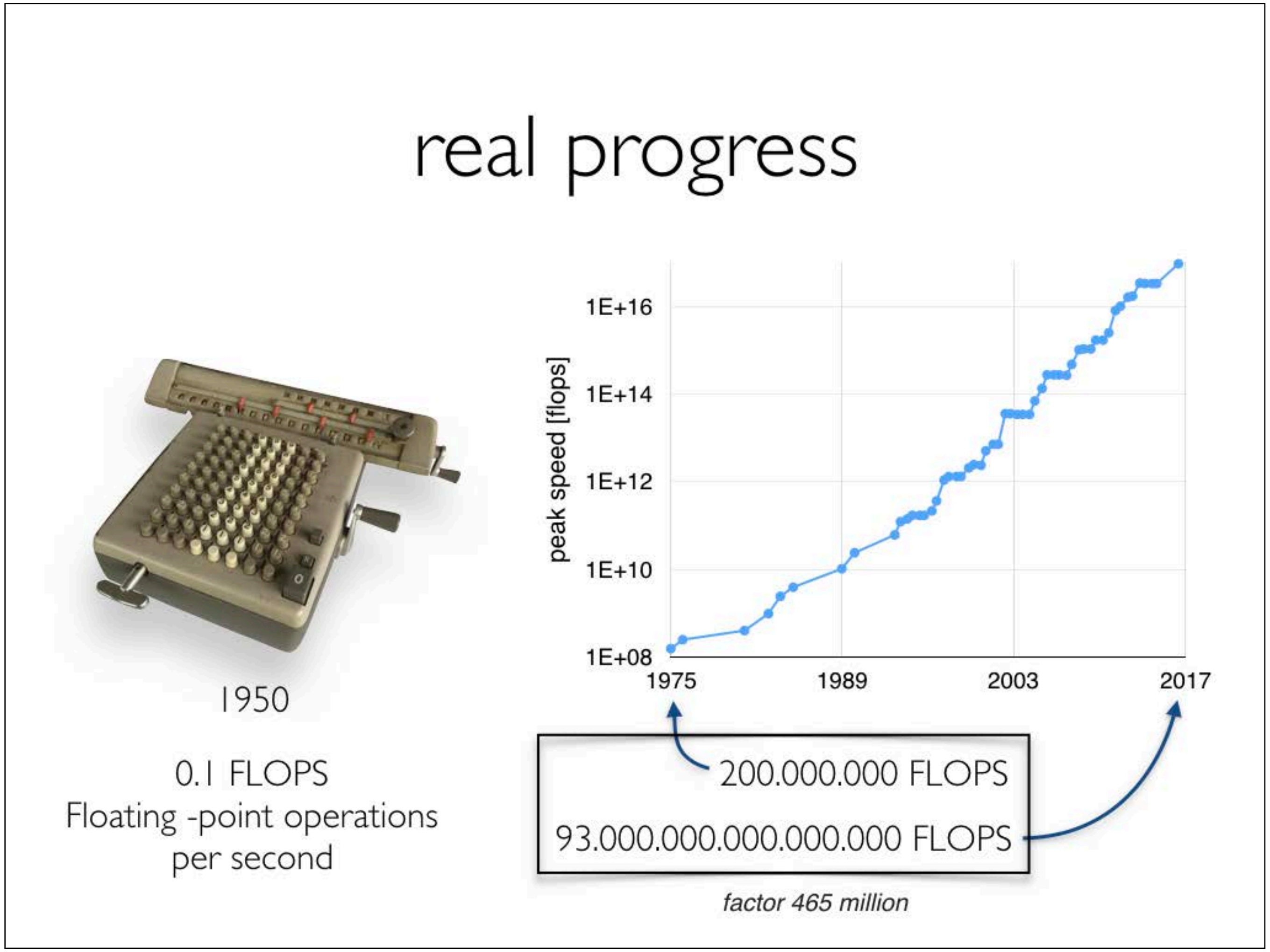
real progress

- elasto-hydrodynamic-lubrication (EHL)
- cavitation
- commutation

But, we did of course make some real progress, especially in the areas of:

- Elasto-hydrodynamic deformation and lubrication;
- Cavitation;
- and commutation.

But, the progress was not achieved because we became more intelligent or better designers. We simply have stronger computing powers at our disposal.

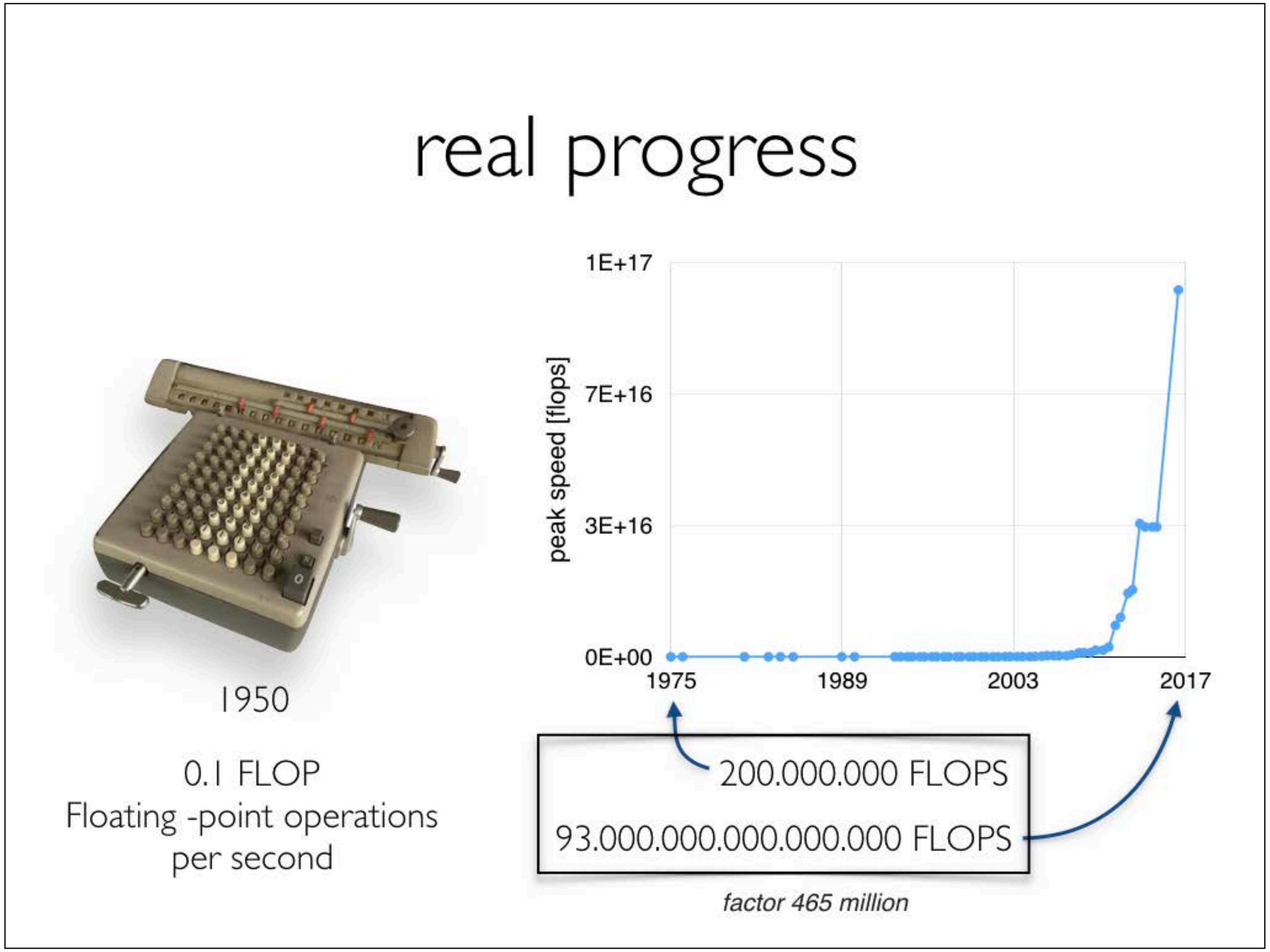


This is the calculating machine I inherited from my father. I estimate it could do about 0,1 floating point operations per second. That is 0,1 flops.

Nowadays, we have unparalleled computing powers available.

- Every decade, computers have become over 100 times more powerful.
- In 1975, when I started my studies at the university, computers could already perform 200 megaflops.
- Now the strongest computer in the world can do 93 petaflops. By the way, these computers are in China, not in the US or in Europe.
- That is an increase of a factor 465 million.

Super computers will soon have the strength of exaflops: a million, times a million, times a million calculations per second. Mind you: the vertical axis has a logarithmic scale…

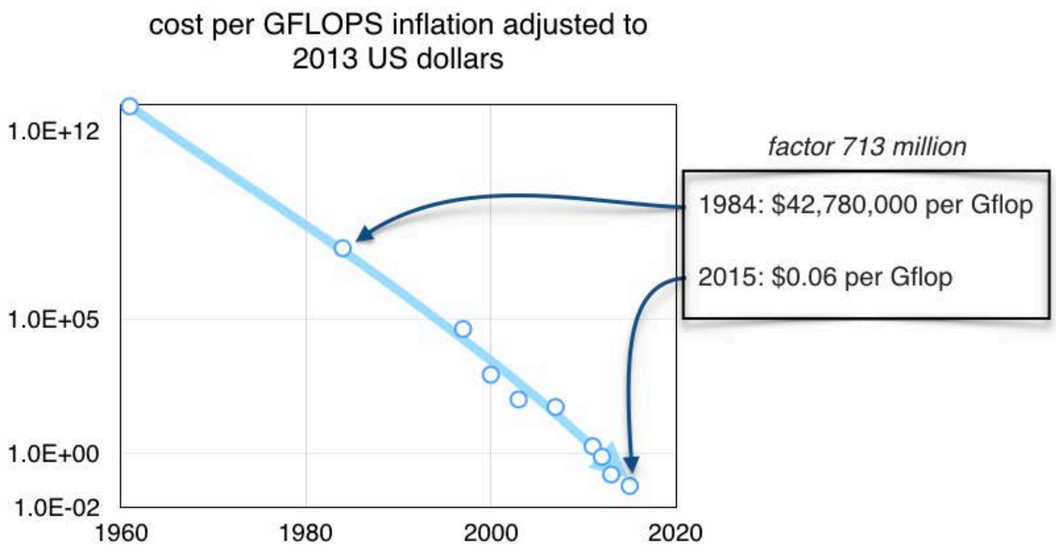


…This is how the graph looks like having a linear scale:

a complete explosion of computational power.

Extremely tempting for engineers, as a weapon in their search for new and better solutions.

real progress

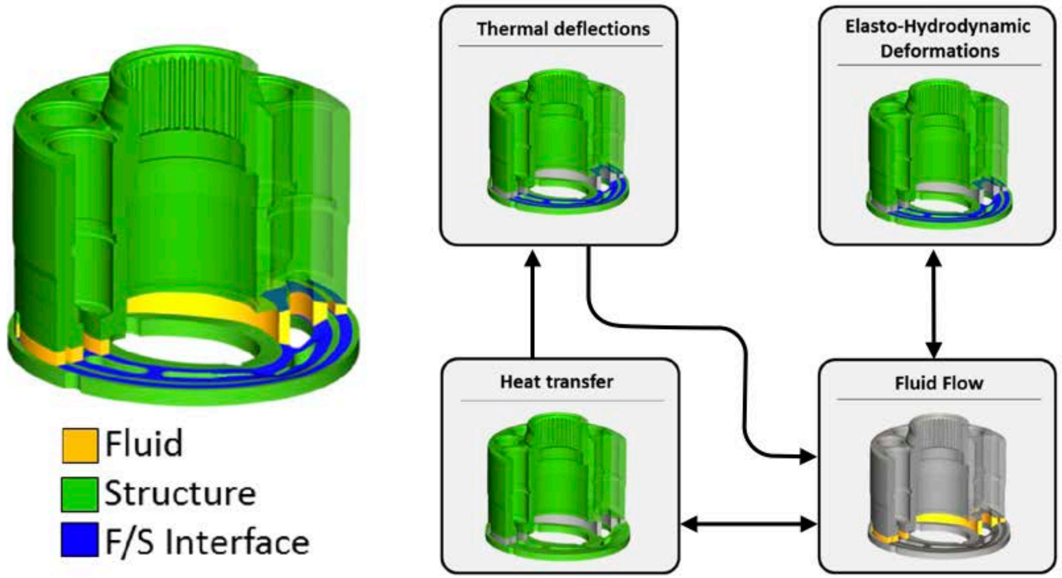


In addition, and that should be no surprise, the costs of computers have decreased, or maybe I should say that they have imploded. Again, the vertical axis of the diagram has a logarithmic scale.

Between 1984 and 2015, the costs have been reduced by a factor 713 million. As a result, engineers and scientists now have a computer power available that I could not dreamed of when I started my career.

And what have we done with all this power?

complex modeling

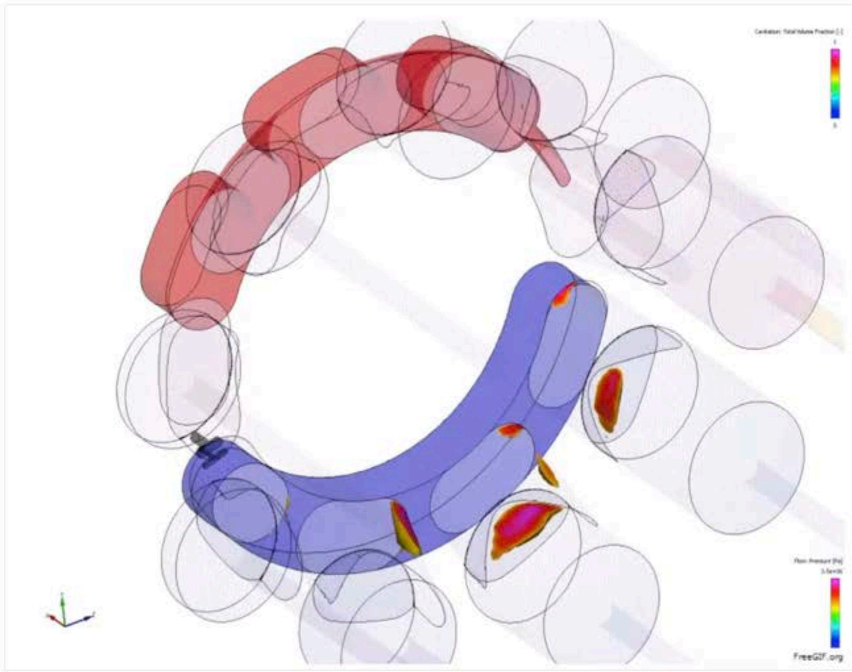


source: Purdue University (Marco Zecchi)

Let me show you a few examples of what progress we made:

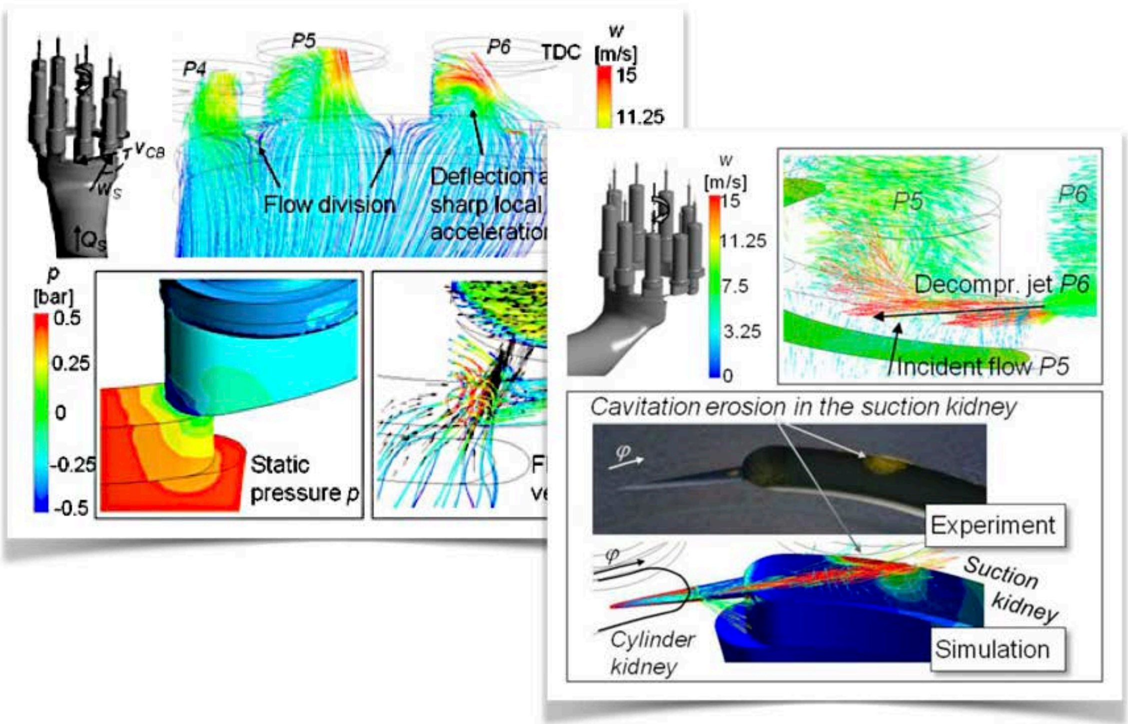
The university of Purdue has managed to include thermal effects in the calculation of the bearing interfaces. It involves a combination of a structural analysis of the mechanical deformation, a calculation of the fluid flow, a heat transfer model and a calculation of the thermal expansion and deformation. And all of these sub-models are interrelated in various ways

cavitation modelling



source: IFAS RWTH Aachen (Christian Schleihs)

Modern computers also allows us to get a much better understanding of cavitation phenomena, like is shown here in this animation from Aachen University.



source: IFD TU Dresden (Norman Bügener, et al)

Or in these illustrations from the Technical University of Dresden.

However, this is all just knowledge. A lot of knowledge, detailed and very scientific. Good for peer reviewed papers and doctoral thesis. But, it doesn’t necessarily bring us any closer to new designs.

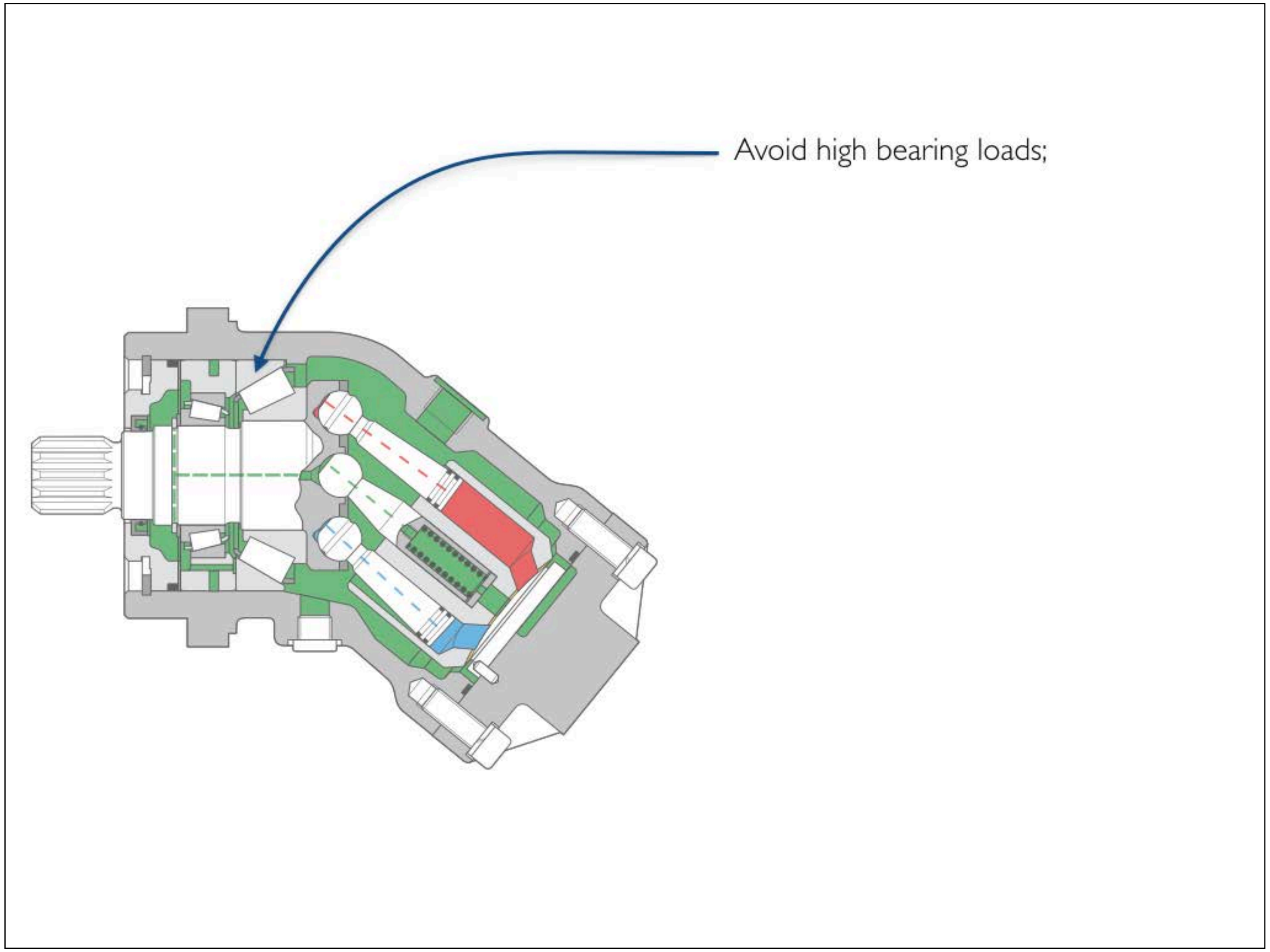
It seems to me, that we have forgotten that computer simulation is not a goal in itself. It is just a means, a technique to get to a better understanding. Simulation can even become an excuse not to start designing, because there is always a deeper, more detailed and sophisticated level to dig into. Simulation makes you number-fetished and short-sighted.

Therefore, all you number-obesed and simulation-obsessed engineers: come out of your deep and dark mines and step into the bright lights of the real world of machine design. I will give you a hand, and lead you through the labyrinth…

problems to avoid

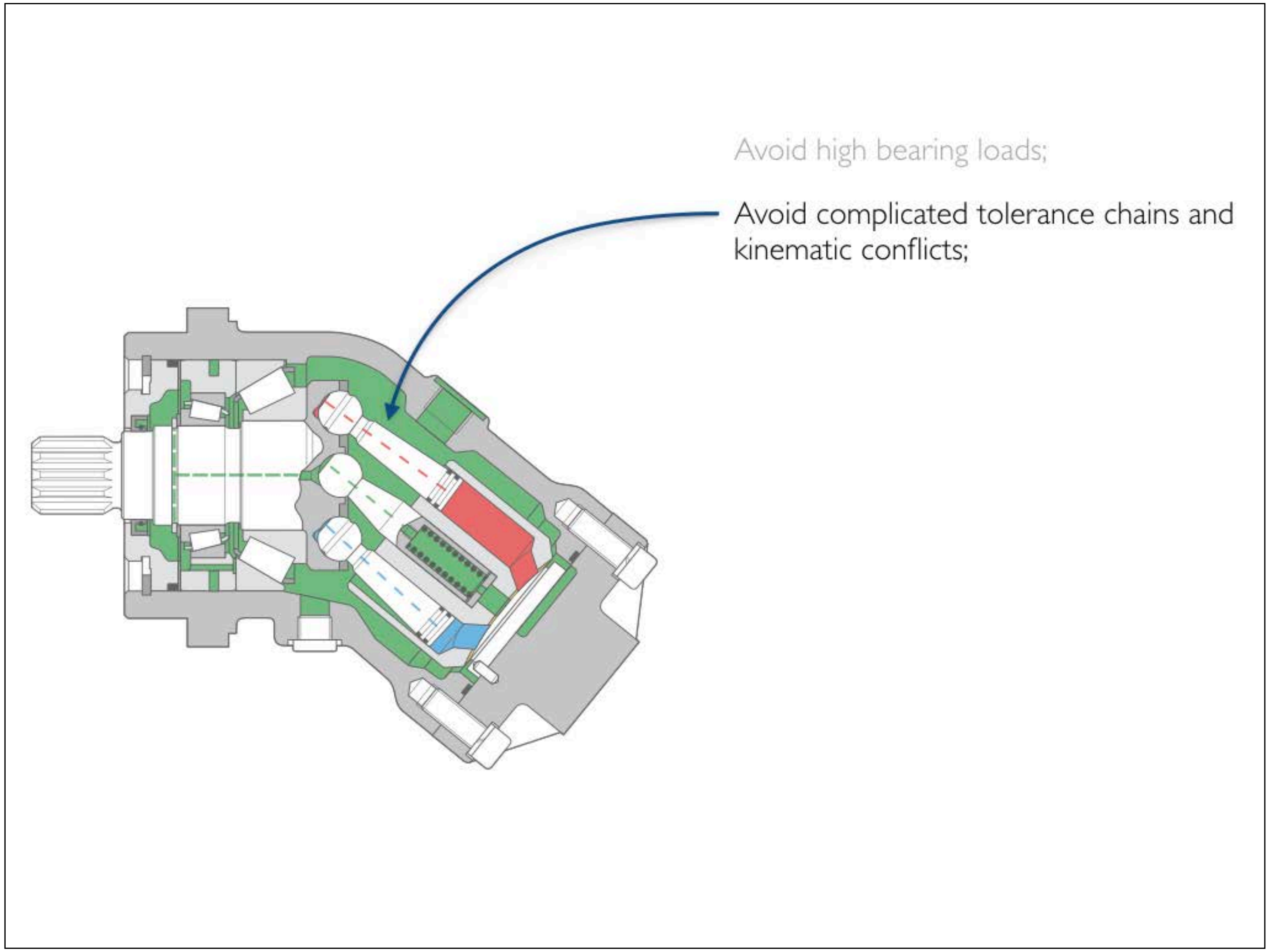
the via negativa in pump design

…through the maze of problems to avoid. And these are the problems of current hydrostatic machines:



This is the first problem. In bent axis machines, the bearings have to take the full hydrostatic load of the rotating group. This results in friction, and also in overheating, noise issues and a reduced lifetime.

Therefore: avoid high bearing loads



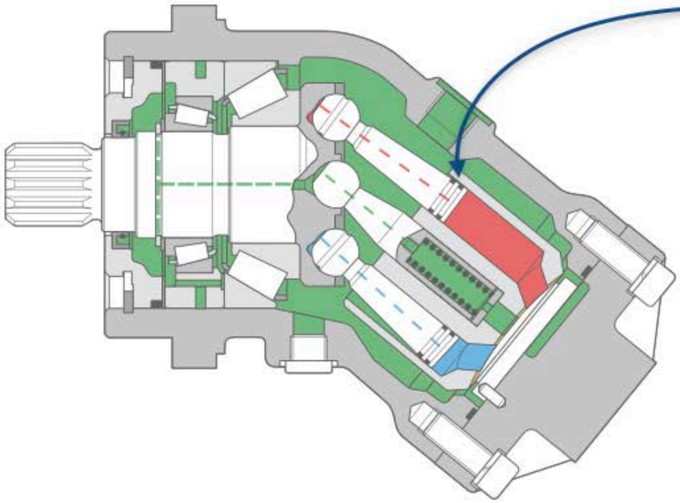
A second problem area is the tolerance chain. Especially this design has a rather complicated tolerance chain, which can easily result in kinematic conflicts. Kinematic conflicts always result in friction and wear.

Avoid them.

Avoid high bearing loads;

Avoid complicated tolerance chains and kinematic conflicts;

Avoid piston rings;



Bent axis machines, and also some radial piston machines, have piston rings. Piston rings are difficult components. They are never 100% balanced and therefore create a substantial friction between the piston and the cylinder.

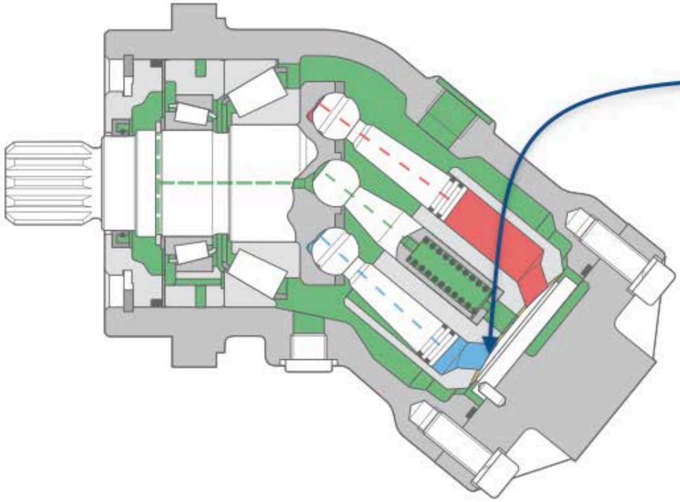
If possible: avoid piston rings.

Avoid high bearing loads;

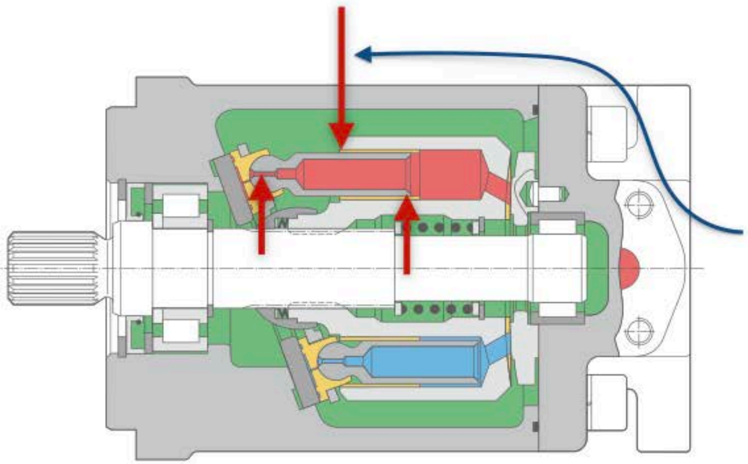
Avoid complicated tolerance chains and kinematic conflicts;

Avoid piston rings;

Reduce the risk for cavitation;



Constructions with a large tilt angle of the barrel, like this bent axis machine, suffer from small opening areas of the barrel ports and of high piston accelerations. These machines have a high risk for cavitation. The small port openings also increase the flow resistance, and therefore create an additional pressure drop and efficiency reduction.



Avoid high bearing loads;

Avoid complicated tolerance chains and kinematic conflicts;

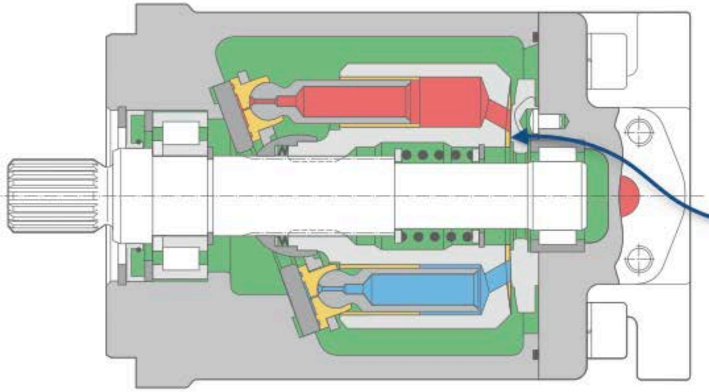
Avoid piston rings;

Reduce the risk for cavitation;

Avoid lateral loads in sliding interfaces;

In slipper type machines, one of the key problems is the high lateral 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.



Avoid high bearing loads;

Avoid complicated tolerance chains and kinematic conflicts;

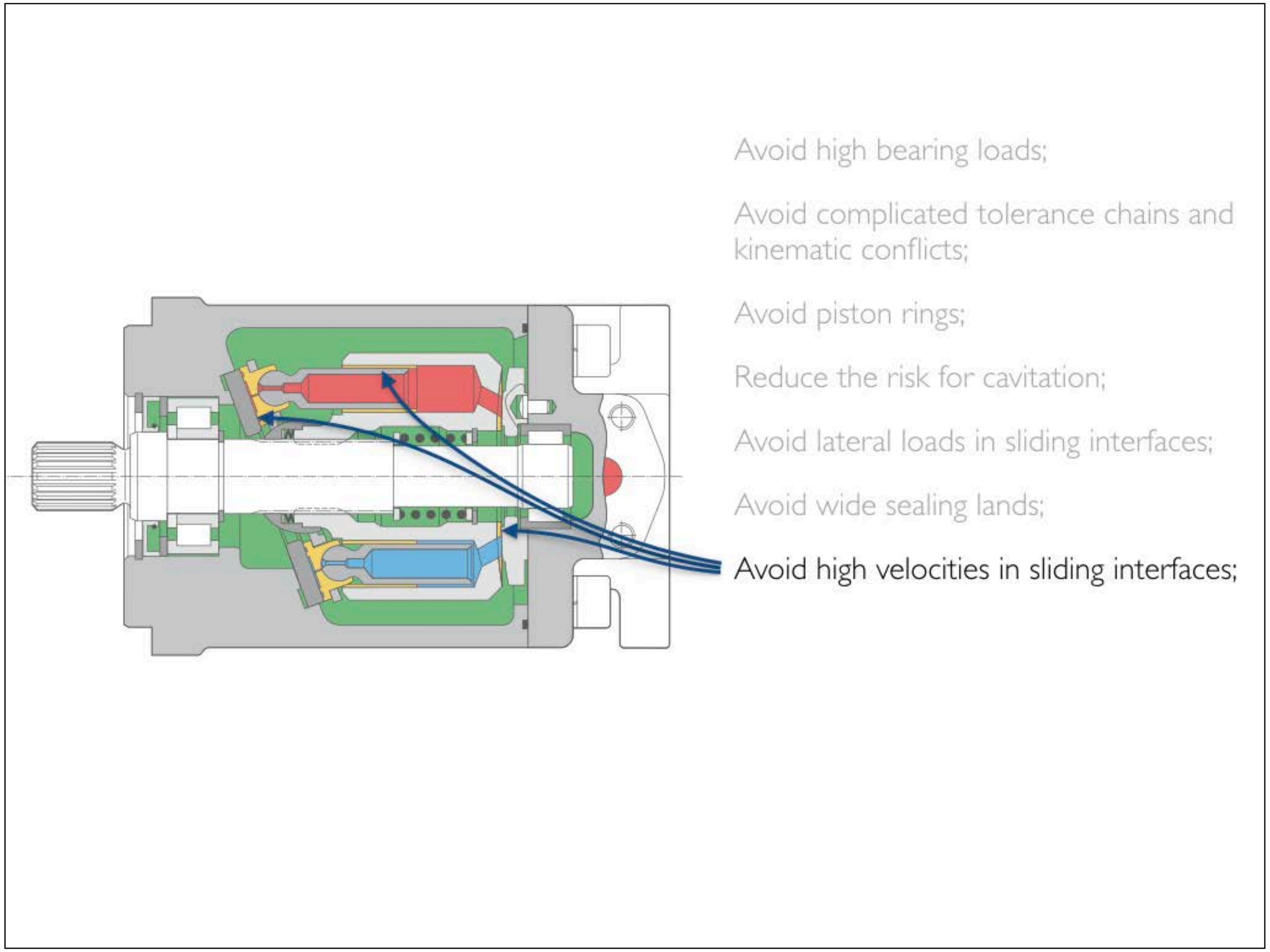
Avoid piston rings;

Reduce the risk for cavitation;

Avoid lateral loads in sliding interfaces;

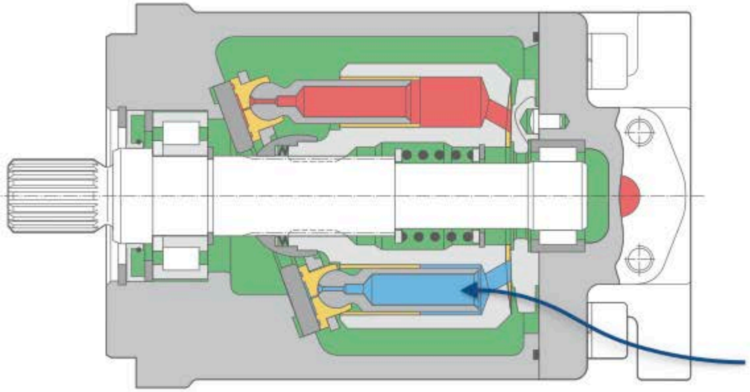
Avoid wide sealing lands;

We also strongly recommend to avoid wide sealing lands. The phenomena in sealing and bearing interfaces are still not fully understood. But, it is certain that wide seal lands increase the risk of over- or under-balancing. This is one of the most crucial points in the design of hydrostatic machines.



Piston pumps and motors are positive displacement machines. They always have sliding interfaces, and thus viscous friction. As such, viscous friction can not be avoided. But it can be minimized, simply by reducing the velocity of the sliding interfaces.

If possible, high shear velocities need to be avoided.



Avoid high bearing loads;

Avoid complicated tolerance chains and kinematic conflicts;

Avoid piston rings;

Reduce the risk for cavitation;

Avoid lateral loads in sliding interfaces;

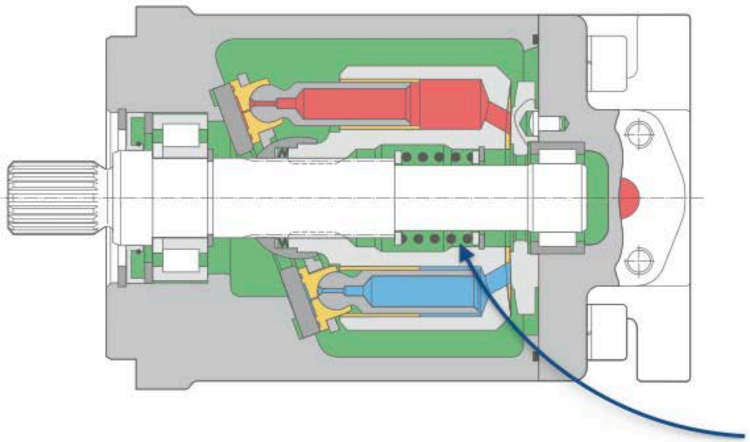
Avoid wide sealing lands;

Avoid high velocities in sliding interfaces;

Avoid large dead volumes;

Dead volumes can also contribute to significant losses. Large dead volumes, like in this example of a slipper type pump, must be avoided.

There is, however, a good reason why the pistons are made hollow. The cavity reduces the piston mass and, therefore, the centrifugal forces.…



Avoid high bearing loads;

Avoid complicated tolerance chains and kinematic conflicts;

Avoid piston rings;

Reduce the risk for cavitation;

Avoid lateral loads in sliding interfaces;

Avoid wide sealing lands;

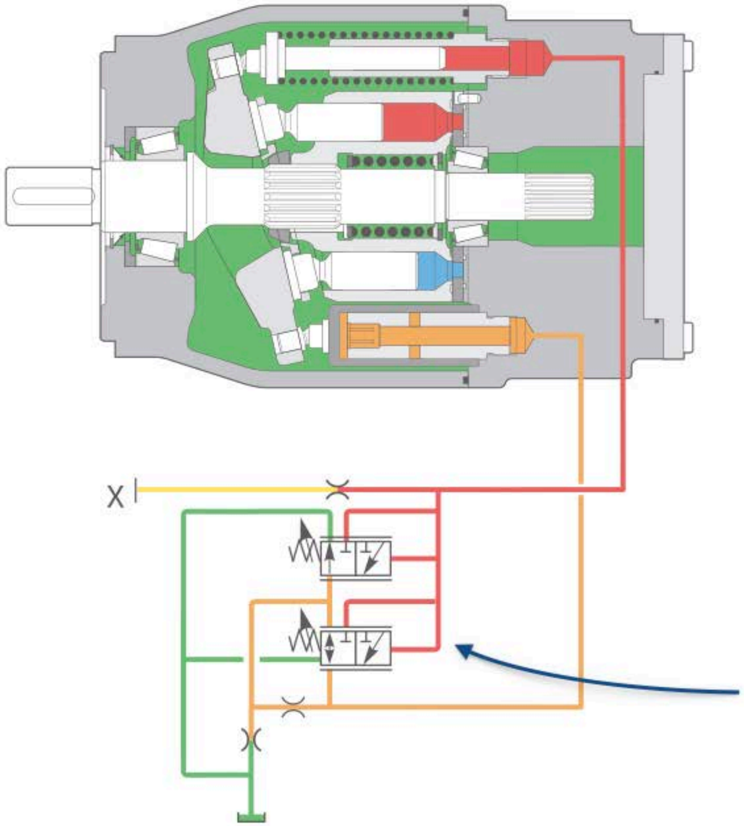
Avoid high velocities in sliding interfaces;

Avoid large dead volumes;

Reduce the barrel spring force;

…This again, helps to bring down the required force of the barrel spring, and thus reduces the friction between the barrel and the port plate.

Yet, despite the large dead volumes of the pistons, the centrifugal forces are still high. The tipping torque is further increased by the piston friction. Both factors require a stronger barrel spring. This clearly should be avoided in a new hydrostatic principle.



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Avoid wide sealing lands;

Avoid high velocities in sliding interfaces;

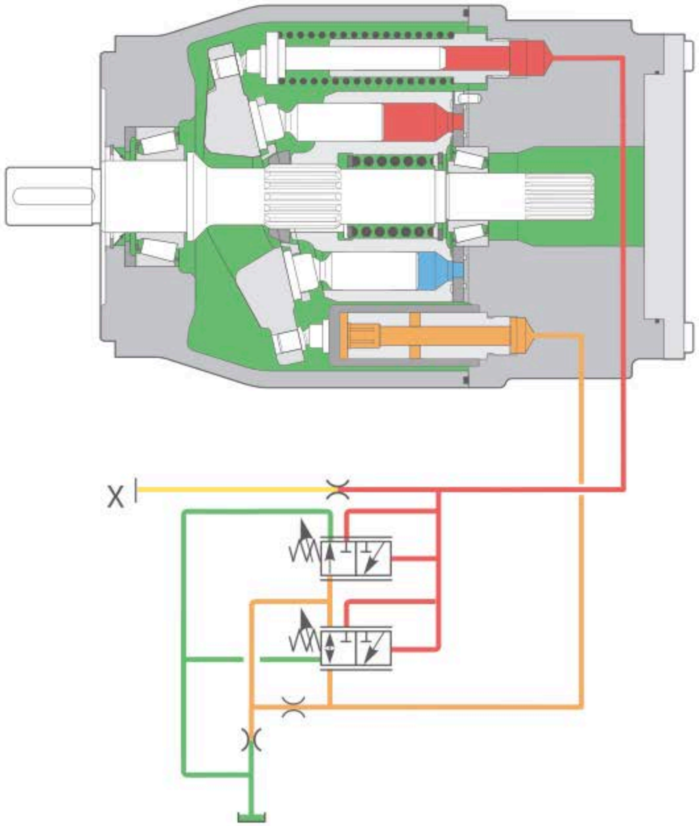
Avoid large dead volumes;

Reduce the barrel spring force;

Reduce the losses of the displacement control

Finally, in current variable displacement machines, the displacement control is extremely inefficient.

I find it hard to understand why the hydraulic industry, and academia, have neglected and ignored these losses for such a long time, even up to this moment.



High bearing loads;

Complicated tolerance chains and kinematic conflicts;

Piston rings friction;

Risk for cavitation;

High lateral loads in sliding interfaces;

Wide sealing lands;

High velocities in sliding interfaces;

Large dead volumes;

Strong barrel spring force;

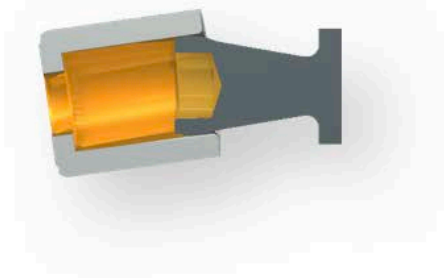
High losses of the displacement control

This is awfully painful, isn't it? Seeing all the things that are wrong.
It is, as if you would come to the doctor and hear that you are ill, very ill indeed, much more than you thought.

I personally don't think that these faults can be cured, simply by small design changes, like new materials or coatings, or by applying waved profiles on the pistons.

Therefore, quite a few years ago, we have already decided to leave the old pump principles, and start afresh with the design of a completely new principle:

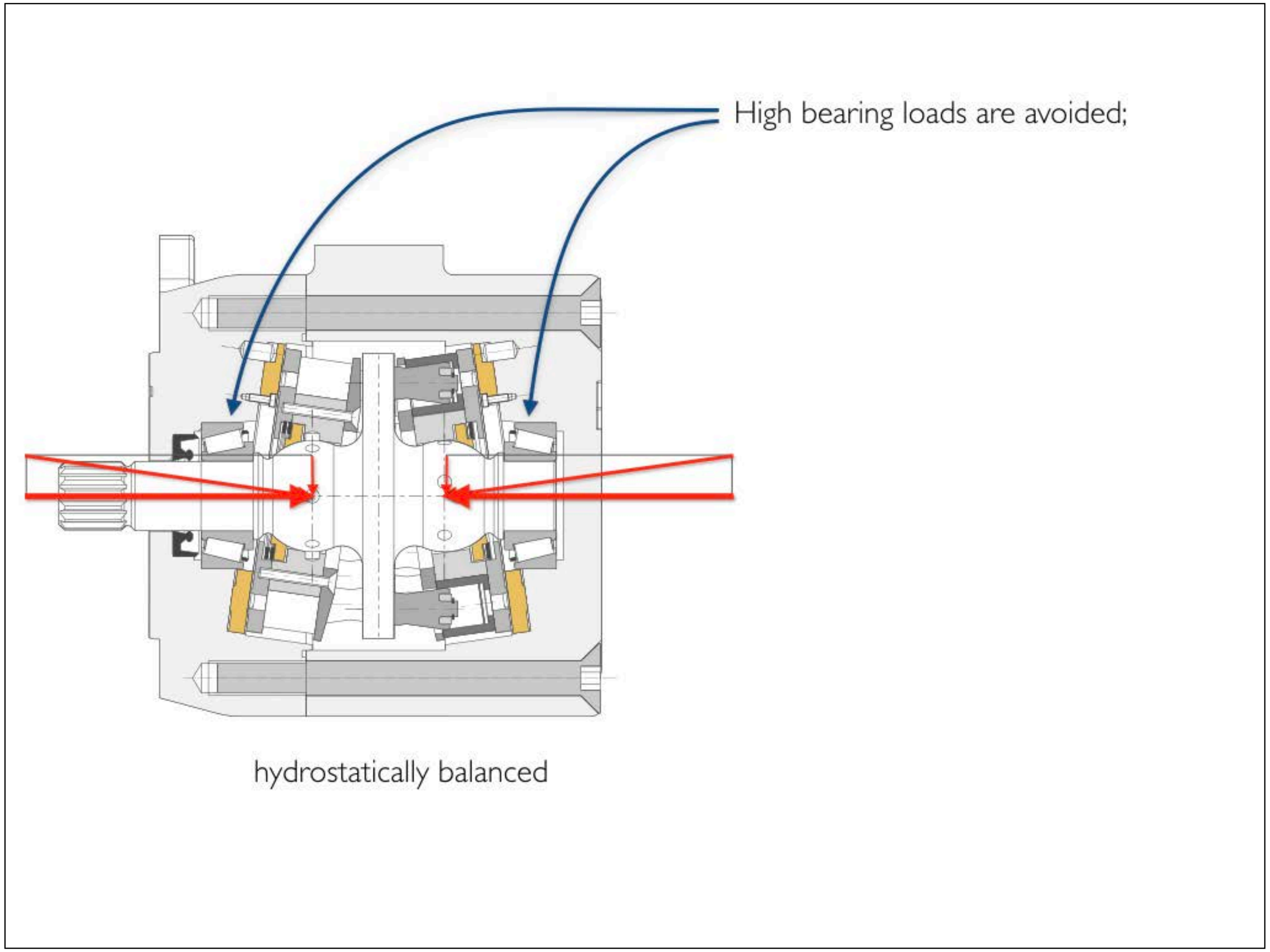
the floating cup solution



…the floating cup principle.

It is by no means the only alternative for current piston pumps, and I strongly believe there is plenty of room for other, innovative designs. But, it is ours. And as it happens, I know a lot about it.

Let me show you how we followed the 'via negativa', and managed to avoid all wrong turns and dead ends in the maze.

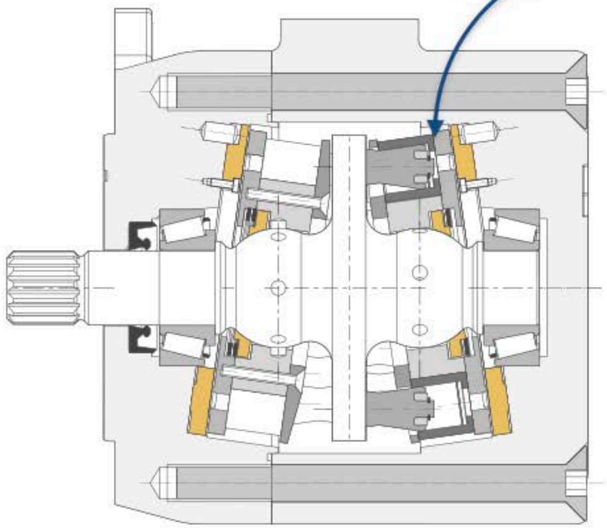


First the bearing load. Floating cup machines have a mirrored construction, in which the axial loads are hydrostatically balanced.

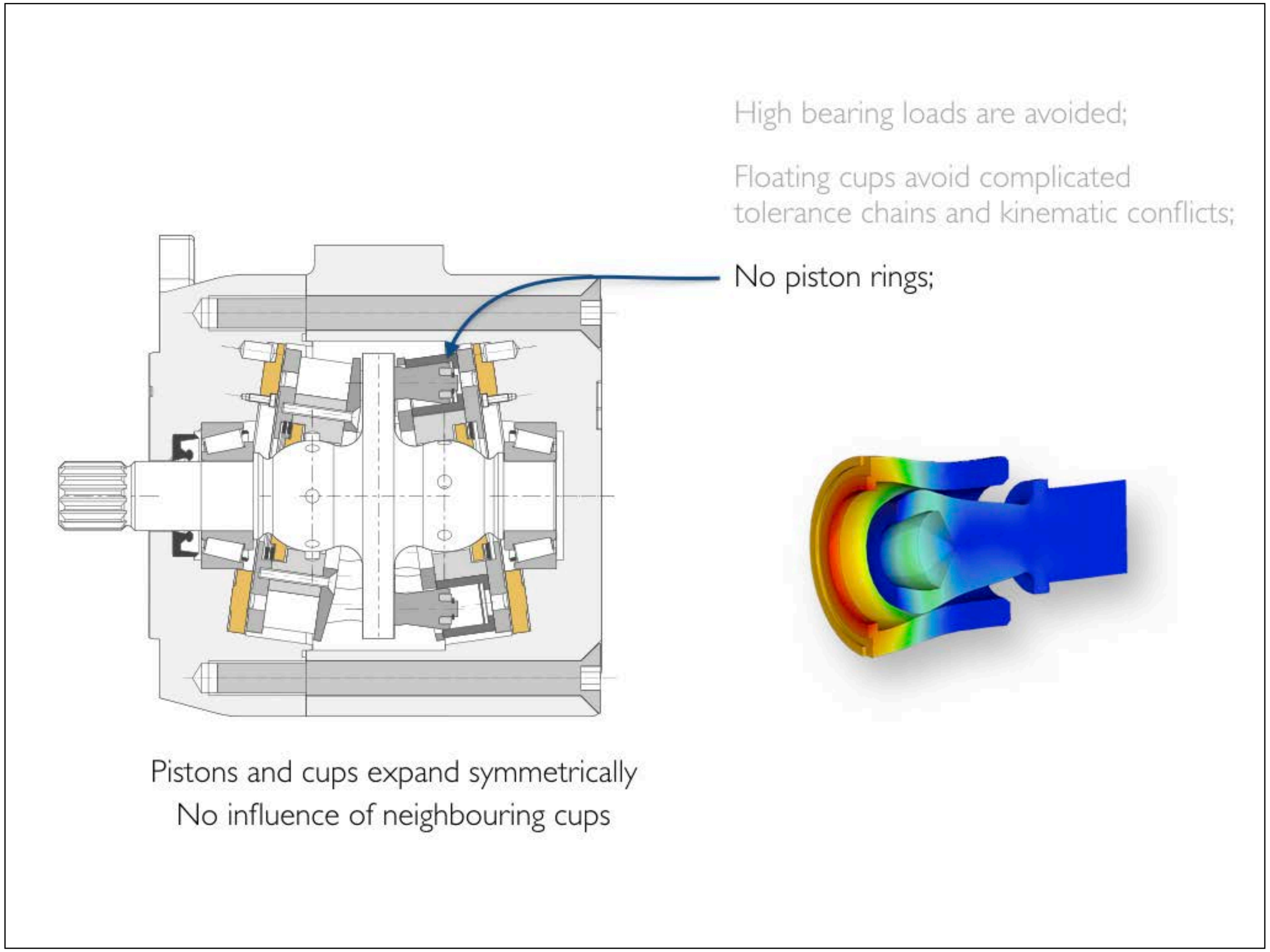
High loads on the roller bearings, as in the bent axis machines, are avoided.

High bearing loads are avoided;

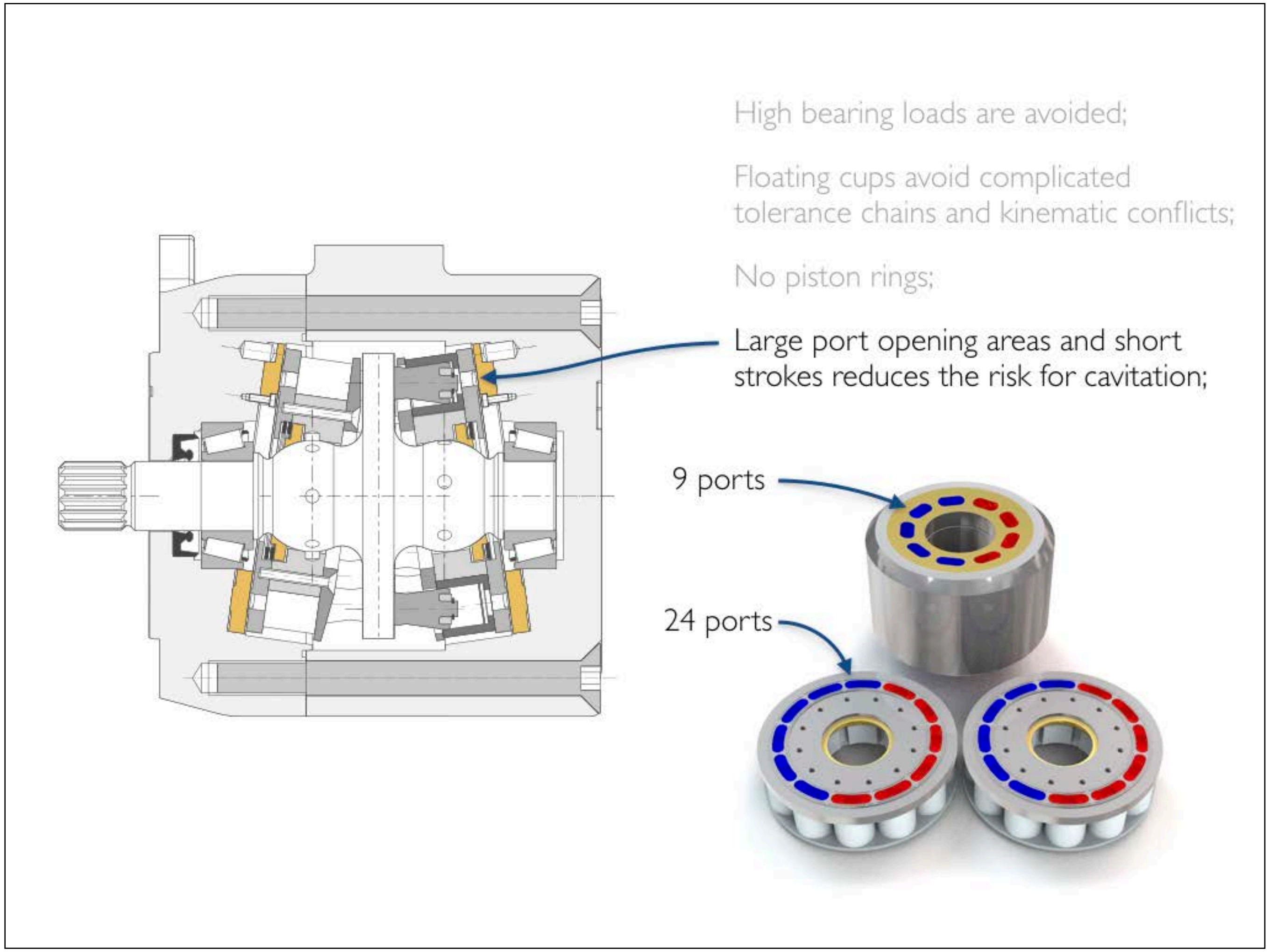
Floating cups avoid complicated tolerance chains and kinematic conflicts;



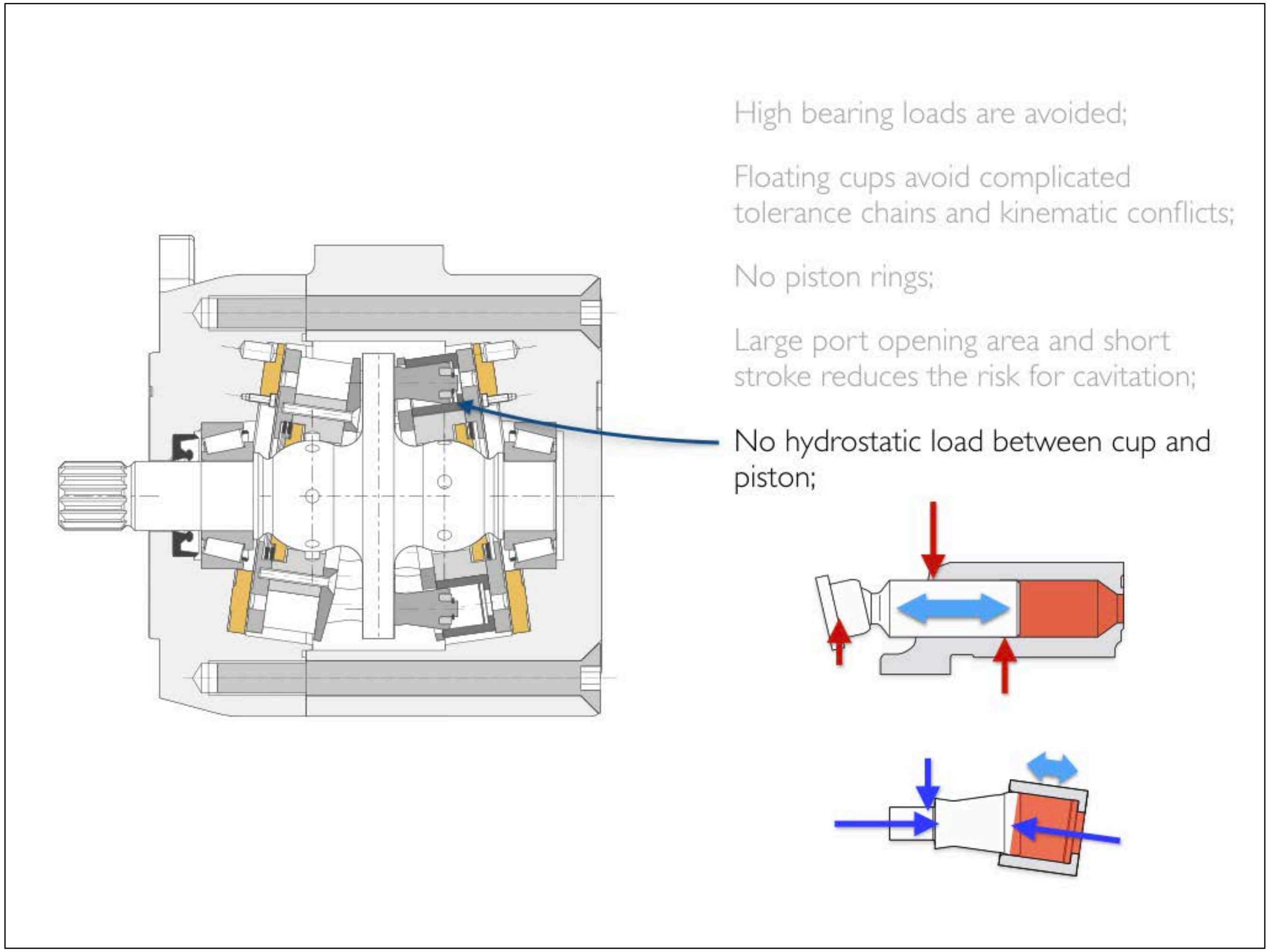
Kinematic conflicts are avoided as well. The cylinders are isolated from the barrel. They have become individual cups, as we call them, which are floating on a rotating barrel plate. Since these cups are free to position themselves on the barrel plate, there is no tolerance chain from one piston to the other, or from one cup to the other.



Piston rings are avoided as well. This is possible because the cups expand equally in all radial directions. By making a small cavity in the piston, the piston crown expands as well, thereby following precisely the expansion of the cup. Piston rings are no longer needed.



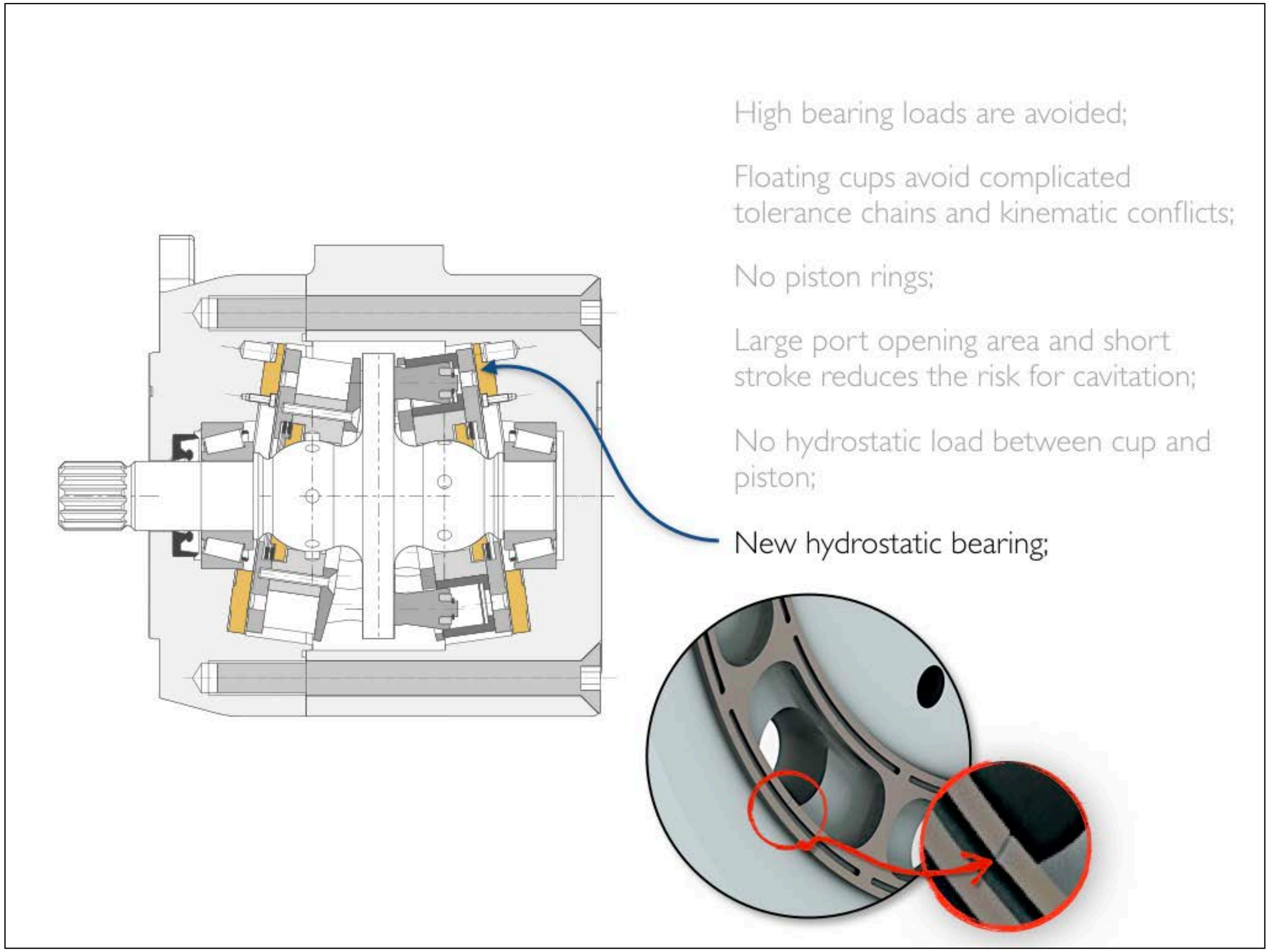
The floating cup principle is a multi piston design, typically having 24 pistons, and therefore also 24 barrel ports. That is about three times as much as in conventional axial piston pumps. Due to the small swash angle, the piston acceleration is also much less, which further reduces the risk for cavitation. The large number of barrel ports also reduces the flow losses.



The floating cup principle completely eliminates the load between the cups and the pistons. It also eliminates high loads on all other bearing interfaces.

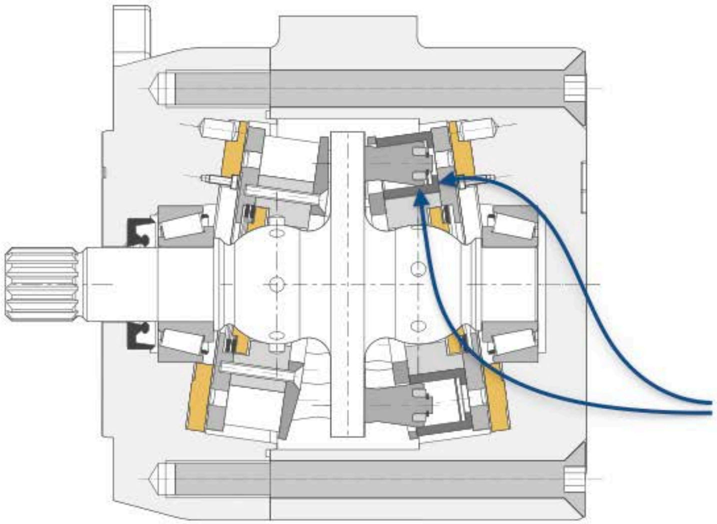
In slipper type machines, high loads are transferred in bearing interfaces. The combination of friction forces and relative movements is a main source of energy losses and wear.

In the floating cup principle, the hydrostatic forces act directly on the pistons, and from thereon on the rotor. There are no relative movements between the pistons and the shaft, no friction losses and wear.



In the floating cup principle, the barrel has a rather large diameter. As a result, the shear velocities in the oil film between the barrel and the port plate is rather high. That is not what we wanted. Moreover, we have not just one, but two barrels, which doubles the problem.

However, we found an escape. We designed a new hydrostatic thrust bearing and face seal. The new construction is robust, very efficient and easy to manufacture.



High bearing loads are avoided;

Floating cups avoid complicated tolerance chains and kinematic conflicts;

No piston rings;

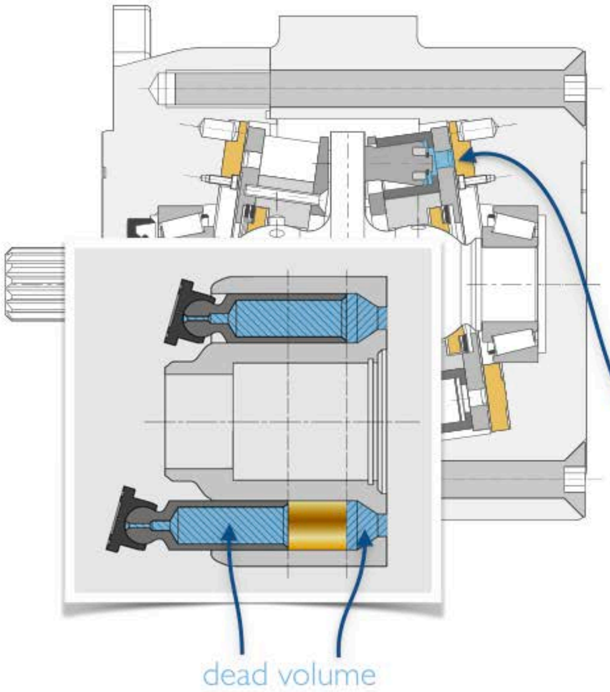
Large port opening area and short stroke reduces the risk for cavitation;

No hydrostatic load between cup and piston;

New hydrostatic bearing;

Low velocities in other sliding interfaces

In all other, remaining sliding interfaces, like, for instance, between the cups and the barrel, the shear velocities are so low that the viscous losses can be neglected.



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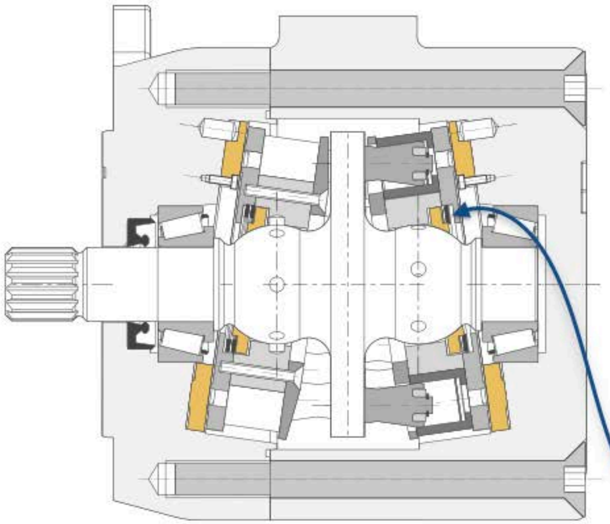
No hydrostatic load between cup and piston;

New hydrostatic bearing;

Low velocities in other sliding interfaces

minimum dead volume

We also managed to reduce the dead volume to a minimum, being much smaller than in current slipper type pumps



light cups + small stroke + no friction

⇒ small tipping torque

⇒ light barrel spring

High bearing loads are avoided;

Floating cups avoid complicated tolerance chains and kinematic conflicts;

No piston rings;

Large port opening area and short stroke reduces the risk for cavitation;

No hydrostatic load between cup and piston;

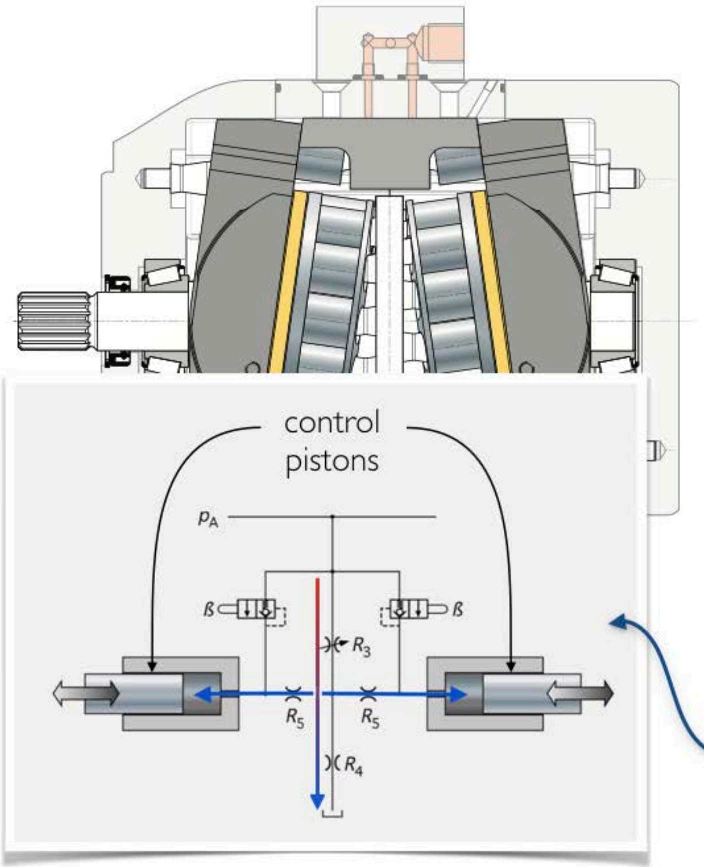
New hydrostatic bearing;

Low velocities in other sliding interfaces

minimum dead volume

minimum barrel spring force

The floating cup principle requires a very light barrel spring. Compared to other axial piston machines, the centrifugal forces, generated by the cups are very small. Also the elimination of friction between the pistons and the cups has strongly reduced the tipping torque. As a result, the barrel spring can be extremely light.



High bearing loads are avoided;

Floating cups avoid complicated tolerance chains and kinematic conflicts;

No piston rings;

Large port opening area and short stroke reduces the risk for cavitation;

No hydrostatic load between cup and piston;

New hydrostatic bearing;

Low velocities in other sliding interfaces

minimum dead volume

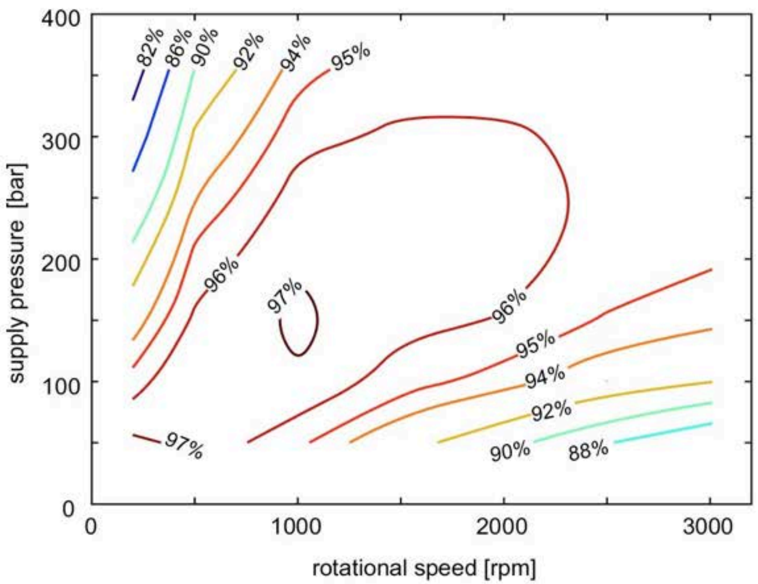
minimum barrel spring force

new, efficient swash plate control and oscillation damping

The last steps on our ‘via negativa’ concerned the swash plate control of the variable displacement pump. We had to find, and we did find, a better, much more efficient solution.

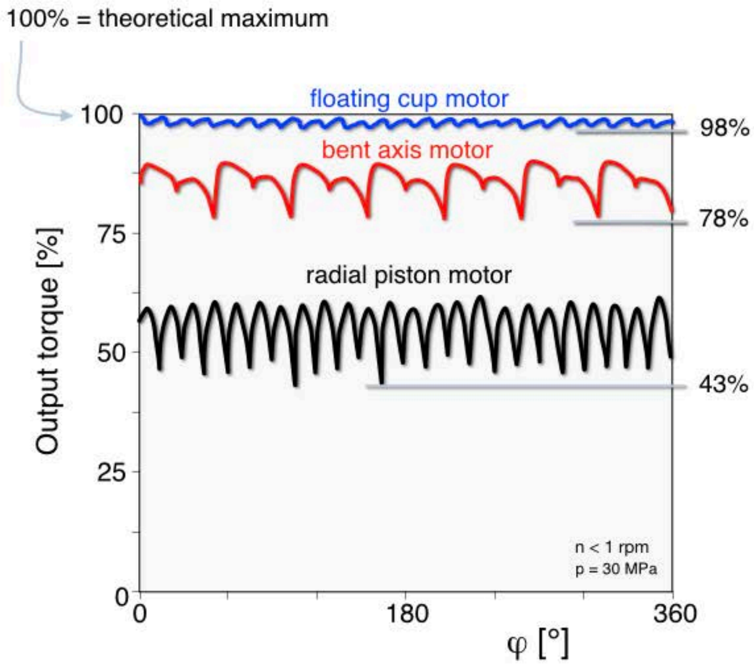
Total efficiency: 97%

measurements Eindhoven University of Technology, FCM24



These are measurements from the Technical University of Eindhoven on a small 24 cc floating cup machine, showing an efficiency of 97% in the best point. This is the total efficiency. The measurement is from 2012. Meanwhile we have reached efficiencies of over 98%.

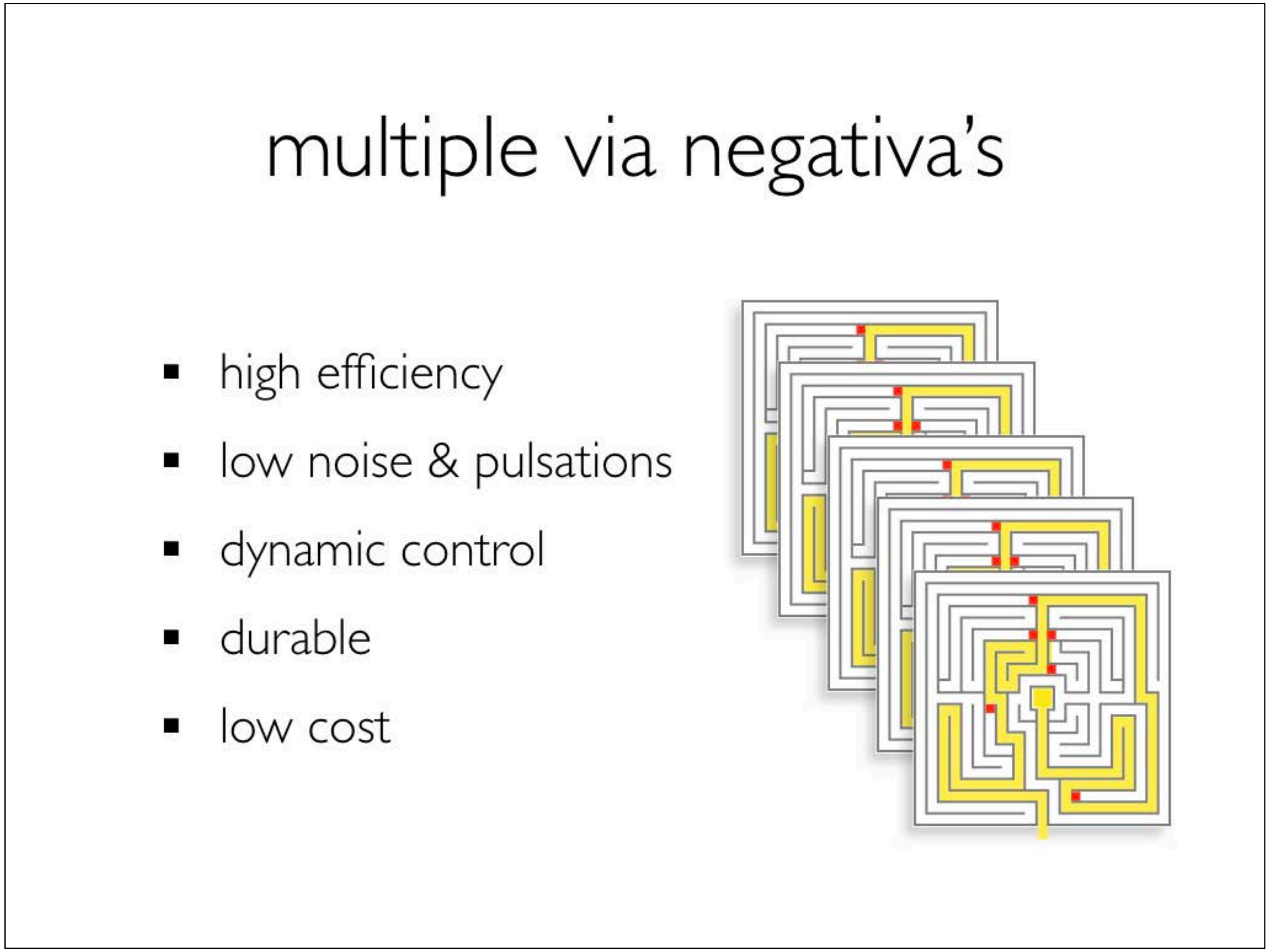
Breakaway torque



The floating cup principle also strongly improves the breakaway torque. This diagram shows the measurement of a bent axis motor during one revolution. Friction losses and the low and odd number of pistons create a situation in which more than 20% of the maximum torque is lost at start-up conditions.

For a radial piston motor, these losses can even by more than 50%.

We also tested the floating cup principle as a motor. The diagram clearly shows the excellent start-up behaviour, as well as the extremely smooth output torque.

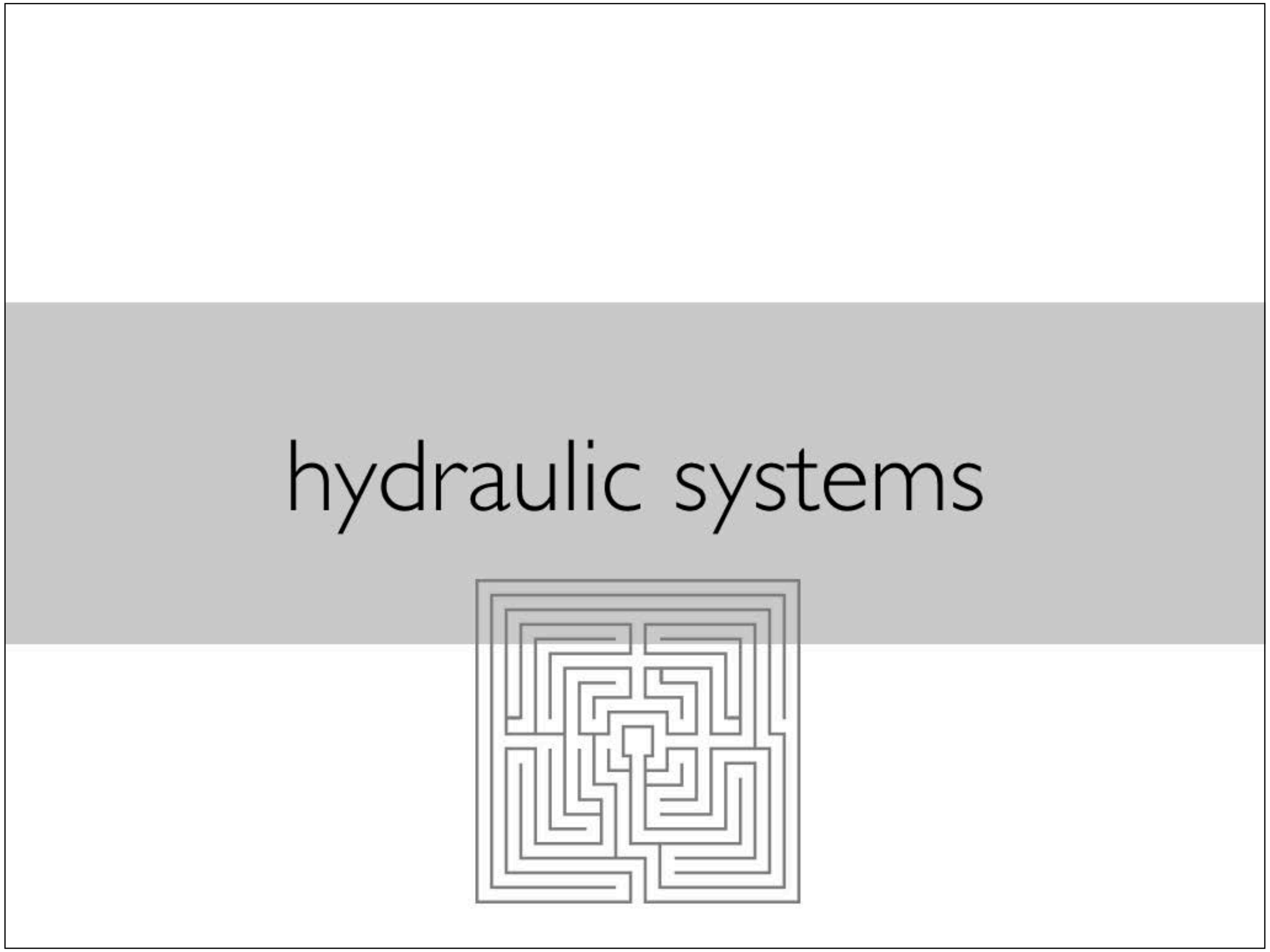


We managed to find a much more efficient pump principle. But we wouldn't have been successful, and bring into production, if we not also managed to improve the other characteristics of the pump as well:

- the noise and pulsation levels;
- the dynamic behavior and stability of the variable displacement pump;
- the durability;
- and the manufacturing costs.

We had to find one single design principle, which could combine all of these advantages. It is like playing 3-dimensional chess.

This was my first example to explain to you the metaphor of the 'via negativa' in design engineering. I explained to you how we first made a detailed analysis of all of the problems in current designs. This analysis showed which problems we had to avoid, and, based on this, guided us to our new solution.



So far our ‘via negativa’ on the component level. Now, let us take it one level higher, and look at systems. Hydraulic systems, of course!

‘The Sandpit’ Sam O’hare

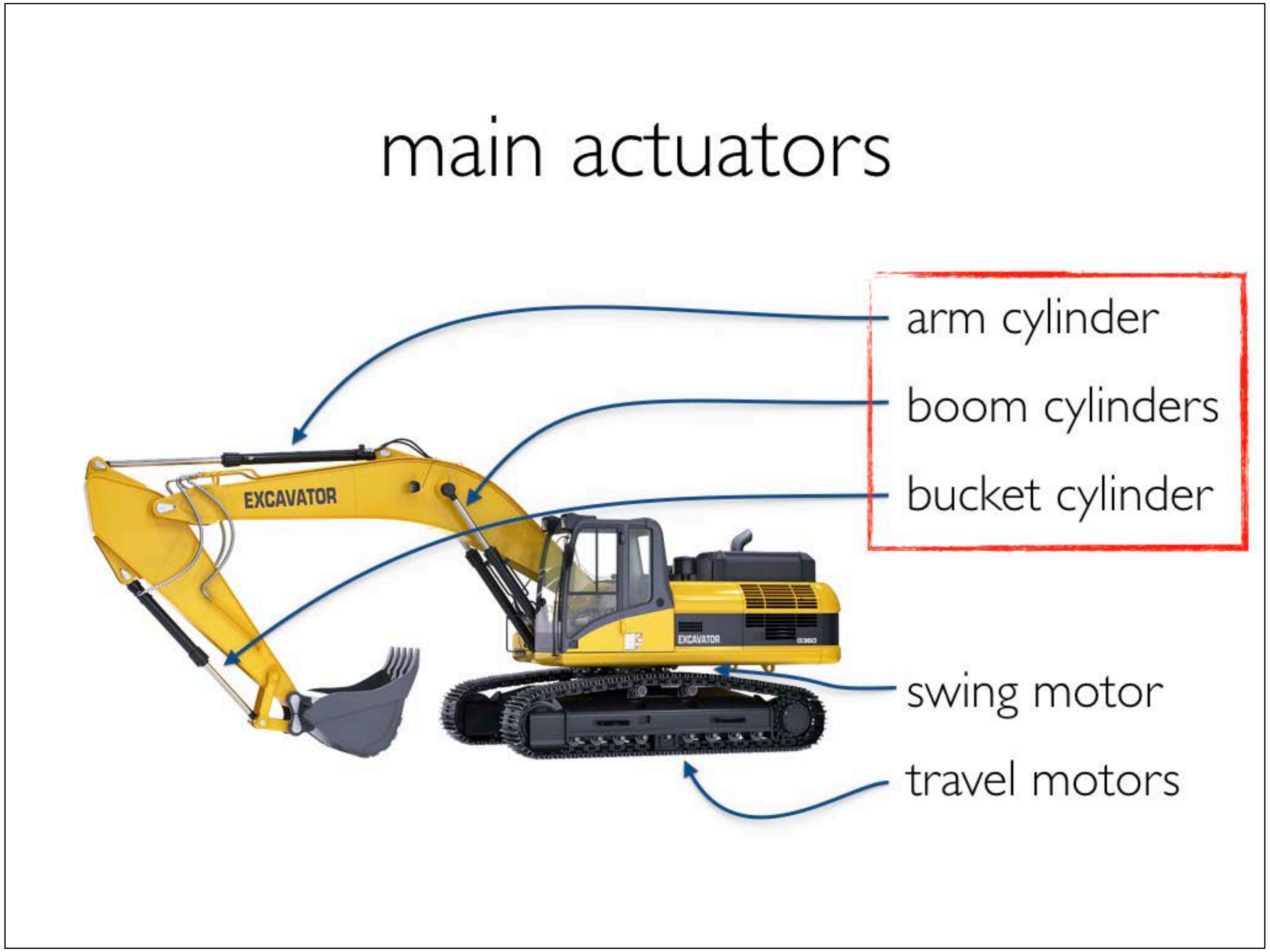
The core business of the hydraulic market are mobile applications: agricultural machines, mining machines and, as shown here, construction machines: excavators, cranes, loaders.

These machines may look like toys, but they are extremely powerful.

These are, most and for all, production machines. They need be:

- safe;
- robust;
- reliable and durable;
- and easy to control.

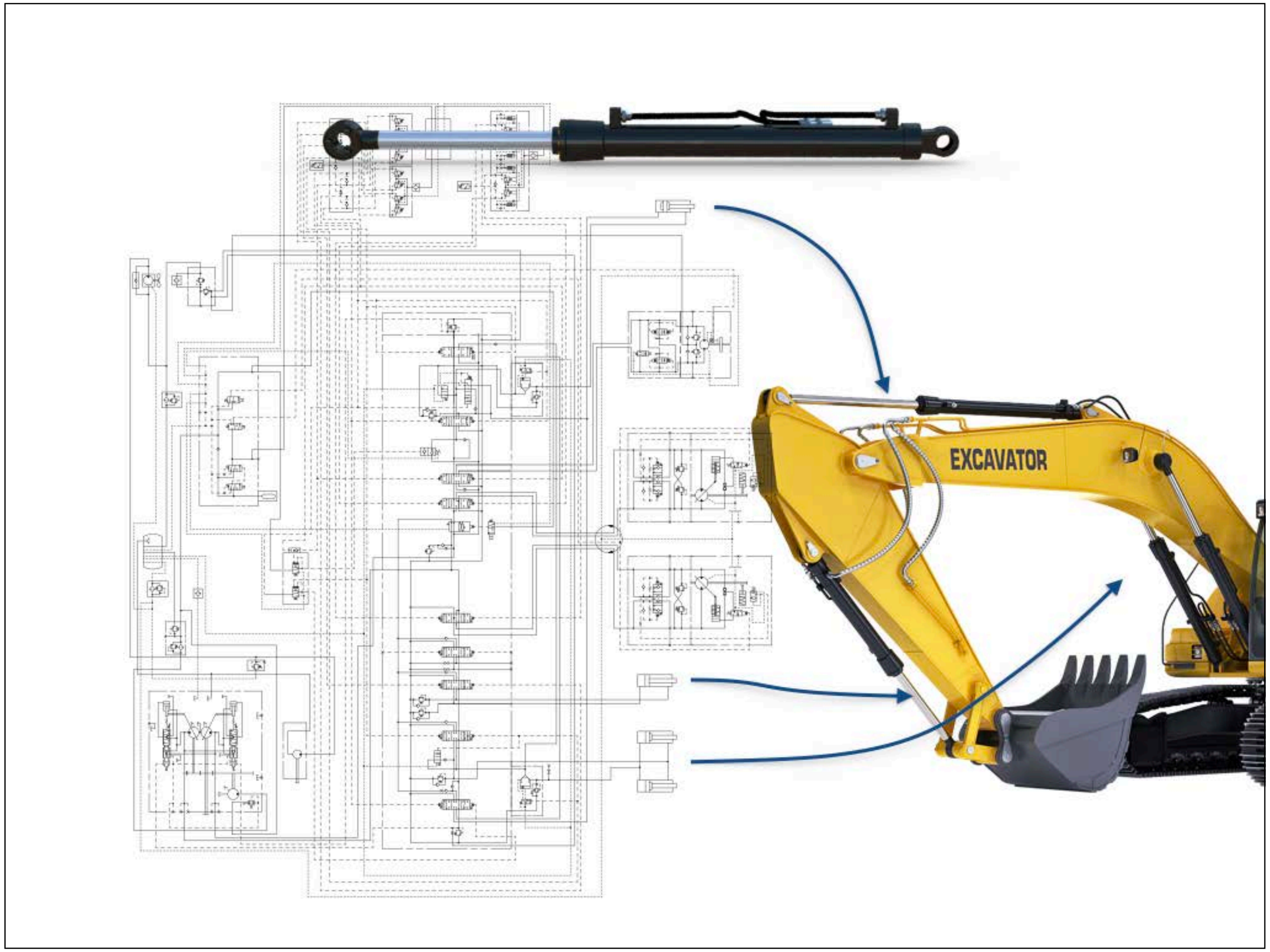
But most and for all they need to have a high productivity



To take this excavator as an example, these are the most important actuators:

- the cylinders of the arm,
- the boom
- and the bucket
- the swing motor
- and the motors to drive the tracks

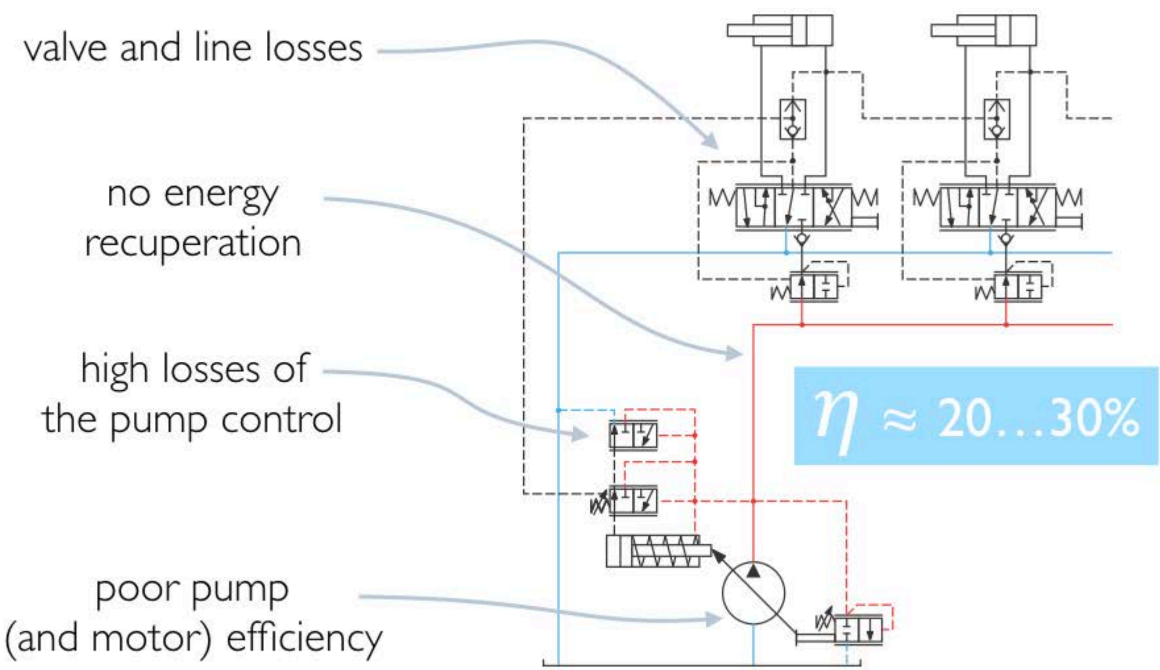
Let me concentrate on the cylinders.



The hydraulic cylinder is the stronghold of the hydraulic industry. Nothing can beat the hydraulic cylinder when it comes to simplicity, force density, reliability and costs.

However, to supply hydraulic power and energy to these cylinders, a very delicate and complicated system is needed.

inefficient



The system is also very inefficient:

- The pump has a poor efficiency at average operating conditions, especially if we also include…
- …the high losses of the pump control;
- In addition energy recuperation is nearly impossible. This is important since the mass of the boom, the arm and the bucket is often more than the load itself;
- But most losses are caused by the proportional valves, the pressure compensators and the hydraulic lines.

On average, the cycle efficiency of these systems is only 20 to 30%.

hydraulic system control

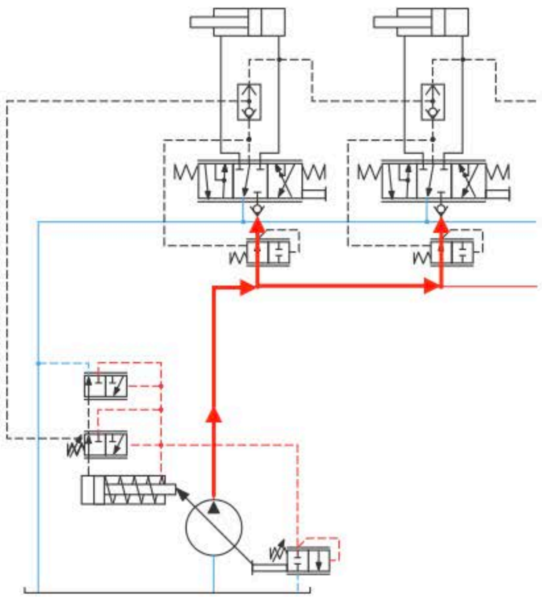
I will not go into details about all the control issues, but there are some that I need to mention.

control:

multiple functions controlled simultaneously by one pump

First of all it is important to understand that in most systems, one single pump supplies oil to multiple cylinders.

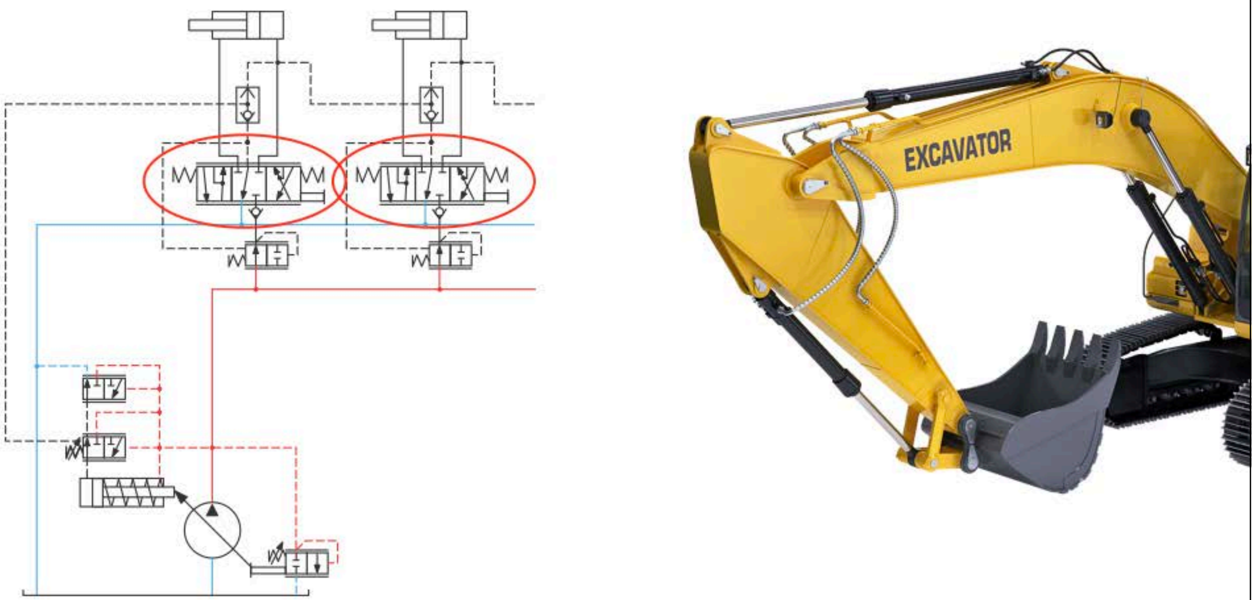
control:
load interference



As a consequence, these systems often suffer from load interference:

the pressure level at one actuator can have a strong, but undesirable influence on the velocity of the other actuators.

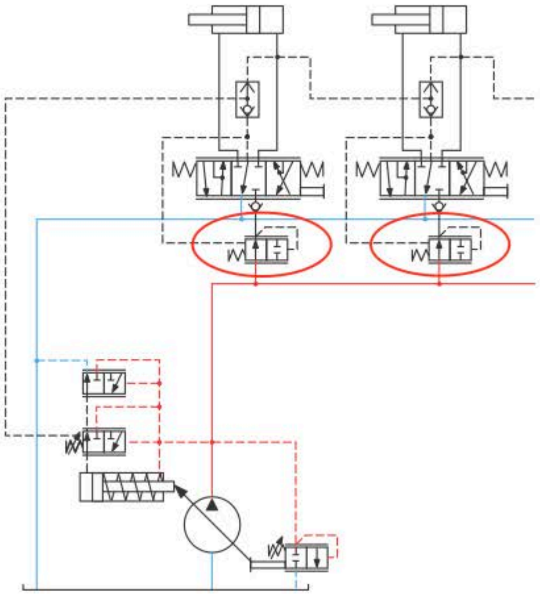
control:
load dependency



Furthermore, you might think that the flow rate is simply defined by the position of the control valve. But the flow is also dependent on the load pressure.

This is called load dependency.

control:
negative damping



In order to avoid some of these problems, load sensing systems with pressure compensators have been introduced. But these systems can result in zero, or even negative damping.

control:

machine parameters change during operation

geometry

oil parameters

excavator position

variable digging forces

operating mass & inertia

The machine parameters constantly change during operation, such as in this example:

- the angular and translational positions of the boom, arm and bucket;
- the oil parameters;
- the excavator position;
- strong variation of the digging forces;
- as well as variations of the operating mass and inertia.

control:

challenging systems and controls

no damping or even negative damping

load interference (cross-talking)

load dependency

non-linear

To summarize:
the control of hydraulic systems is rather challenging:

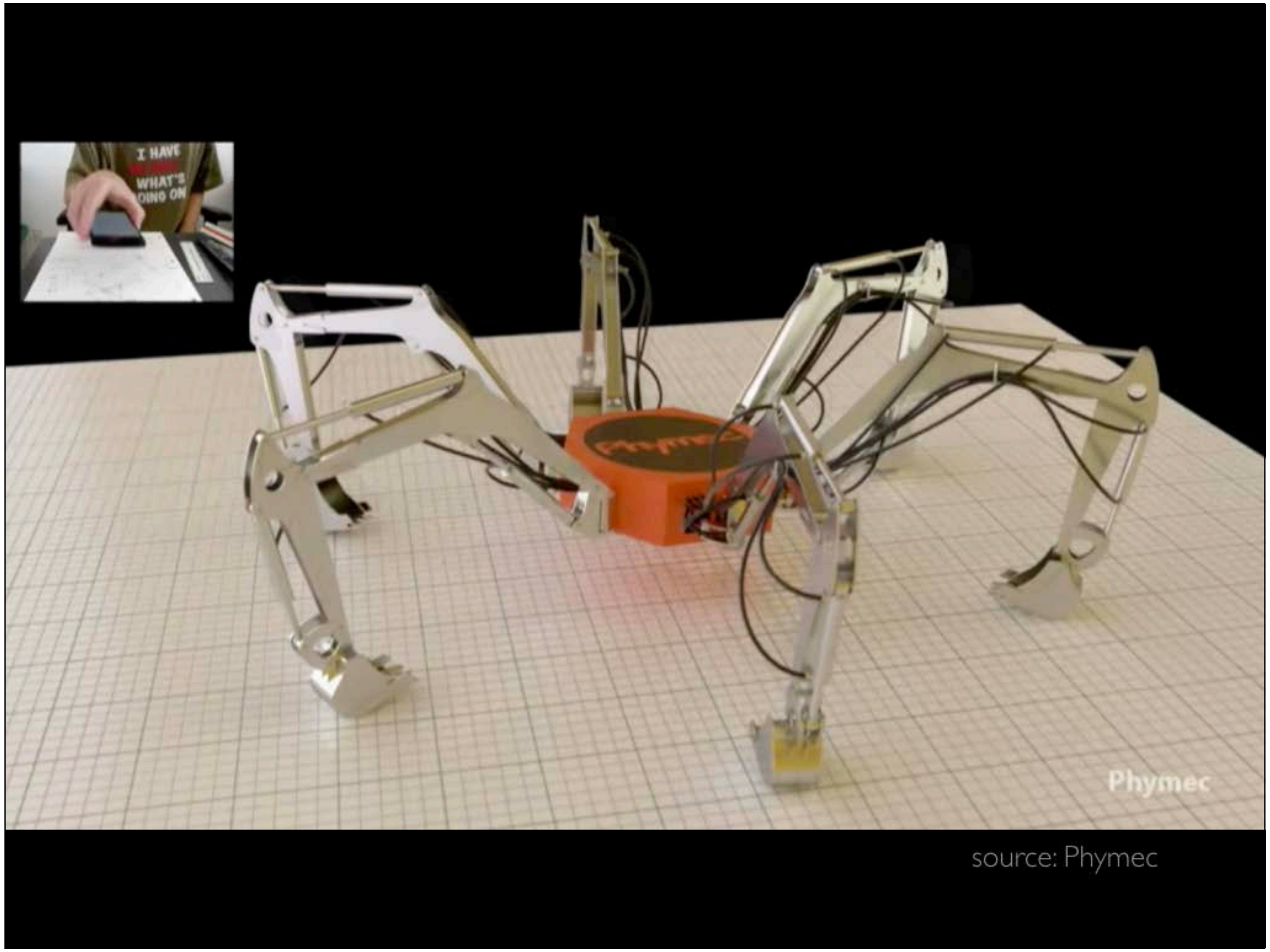
- the damping can be zero or even become negative
- the various actuators can have cross-talking
- often, the actuators suffer from load dependency
- In addition, we are dealing with strongly non-linear systems

Ladies and gentleman from the Dynamic Systems and Control Conference:
Here is a very interesting, but also challenging task for you.

This is were we need your creativity.
But not only creativity!:

This photo is taken in Paris, in 1968.
“power to the imagination” it says.

In 1968, this was the main motto of the sixties revolution. And, up till today, we are still influenced, and maybe also somewhat confused by our desire for creativity, as opposed to the status-quo. Nowadays, with the help of computer animations, this confusion has even become bigger.



3D-animations, like this rendered model of a ‘future excavator’ are further increasing this confusion. The model is controlled by the movement of the iPhone, which you see in the upper left corner. This looks nice, doesn’t it? I can almost hear some students whisper: ‘whow, this is great, I’m going to build one of these.’

source: 'The Mantis', Matt Denton

Something like this, for instance, just to start with?

But this is where we get confused. This looks great, it looks real. It is funny and exciting. But it isn't real. It is also not meant to be real. It is an intriguing and expensive toy.
But sure, it is creative.

Every year, around this time of the year, we have the Dutch Design Week in our home town: a large international festival, conference and market for creative designers.

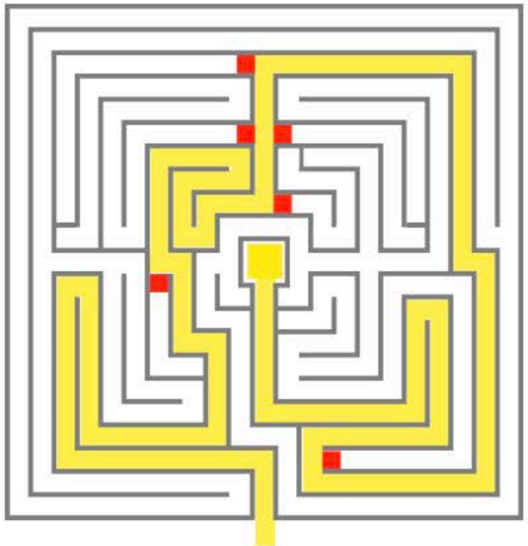
This was one of the creations of last year: it is supposed to be a bike. This is what you might get if imagination is the only thing that counts.

Around the corner of the place, where I found this bike, there was this sign. I thought it was very appropriate.

Creativity is a necessity. I wish would have more creative training at universities. But: is is not enough. What we really need is craftsmanship:

Creativity, combined with skills, knowledge, and talent. ‘Craftsman’ and ‘craftswoman’, that is what we are looking for at our company.

finding a new system



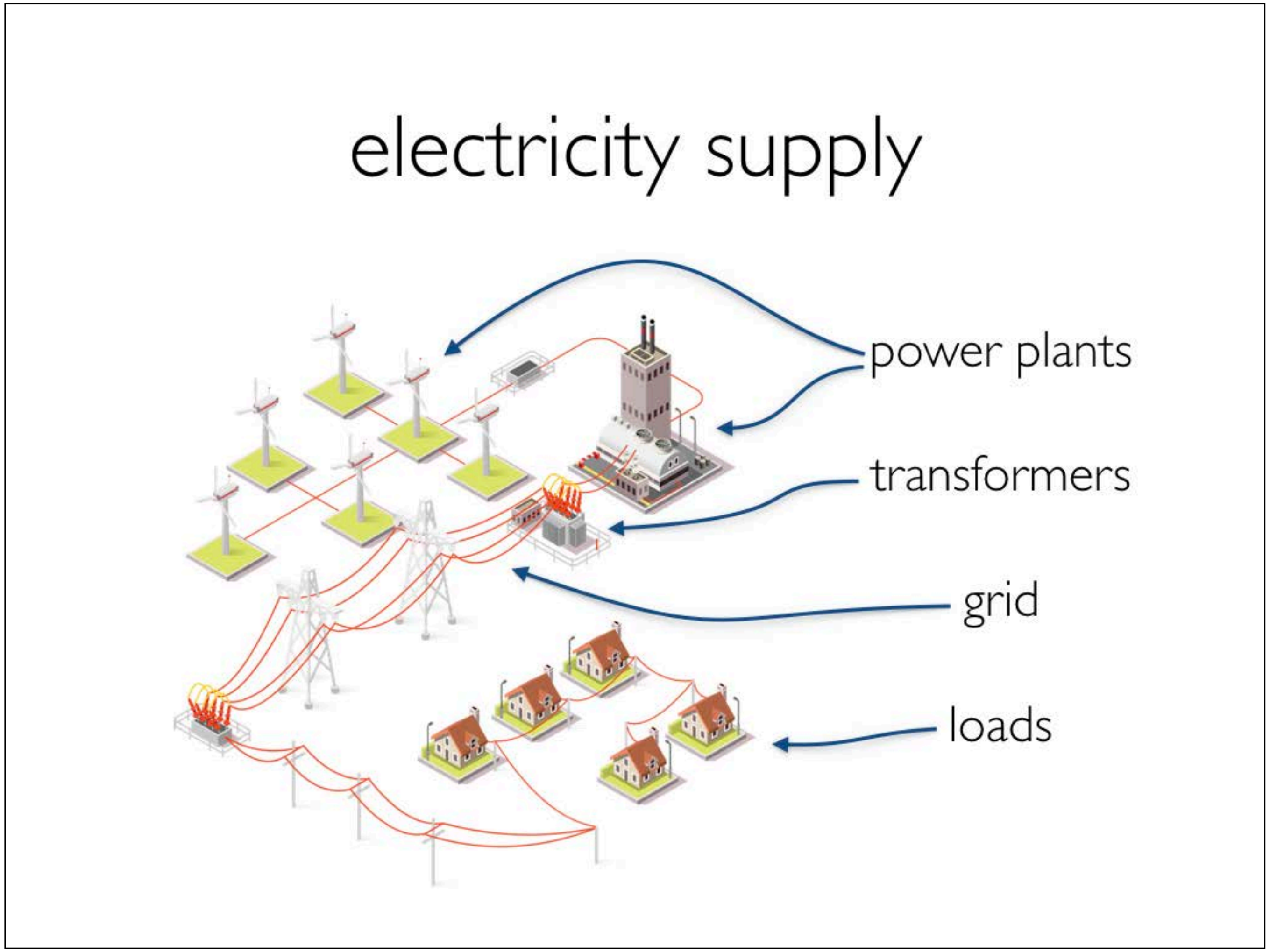
- avoid engine operation at <50% torque load
- develop an efficient pump (and pump control)
- realize power management and energy recuperation
- avoid throttle losses
- develop hydraulic power controllers i.e. transformers

Only then, you can find your way through the maze and choose the right directions.
And this is the path through the maze:
the ‘via negativa’ to find a new hydraulic system approach:

- First of all: Avoid engine operation below 50% of the maximum torque load. Below this value the efficiency of the engines strongly drops. Above you are close to the best point of operation;
- Secondly: develop an efficient pump, and an efficient pump control;
- Next: introduce hydraulic accumulators for power management and energy recuperation;
- Then, of course, we need to get away from valve control, and minimize the throttle losses of these valves;
- And for all of this, we need hydraulic transformers.

Common Pressure Rail (CPR-system)

This is the new system approach we have been advocating for many years: a common pressure rail system.



We all know common rail systems. Our electricity supply is such a system. The backbone of this system is the power grid.

This grid separates the loads from the power plants. Transformers, in all sorts and dimensions, transform electric power from one voltage level to the other.

The grid is as a clear reference for all machines, lights, computers, mobile phones or even electric cars which take power from this grid. These loads don't need to know anything about the power plants. The reverse is also true: the power plants have no responsibility to control the loads. They only need to maintain the voltage level and frequency of the grid, and to supply energy to this grid with the highest efficiency, having the lowest emissions and the lowest costs.

CPR-system

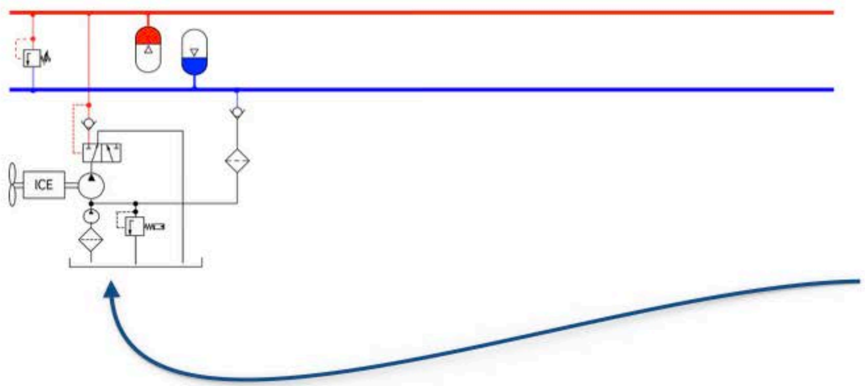
grid:
common pressure rail
(CPR)

A hydraulic common rail system looks the same:

The backbone is now a common pressure rail. Attached to this rail are hydraulic accumulators. These are essential for power management and energy recuperation.

A CPR-system is not a constant pressure system. The pressure level in the accumulators will constantly vary, depending on the power management control strategy and the amount of energy recuperation.

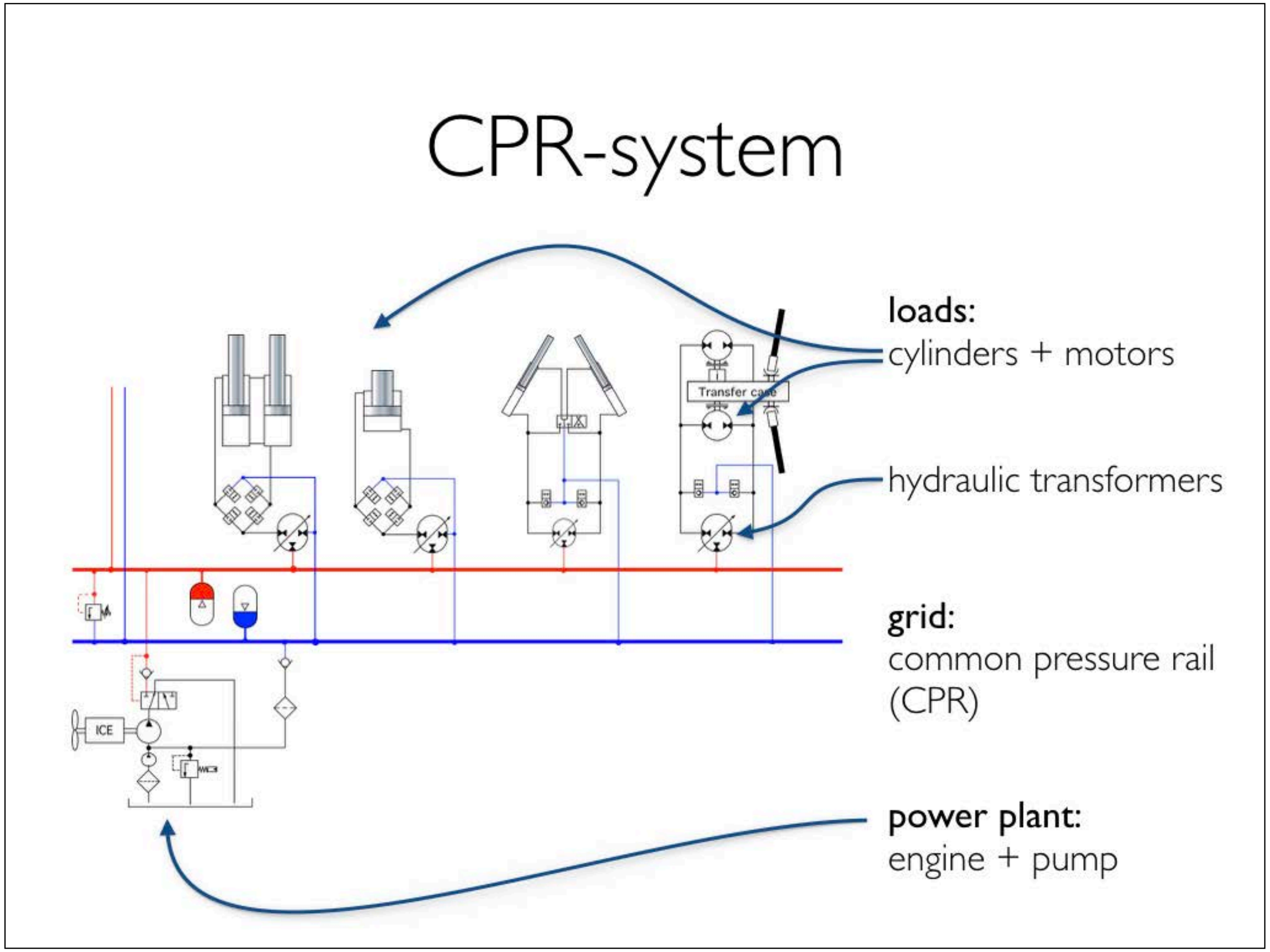
CPR-system



grid:
common pressure rail (CPR)

power plant:
engine + pump

Similar to the electricity grid, we have power plants on the one side. This could for instance be a diesel engine combined with a pump.



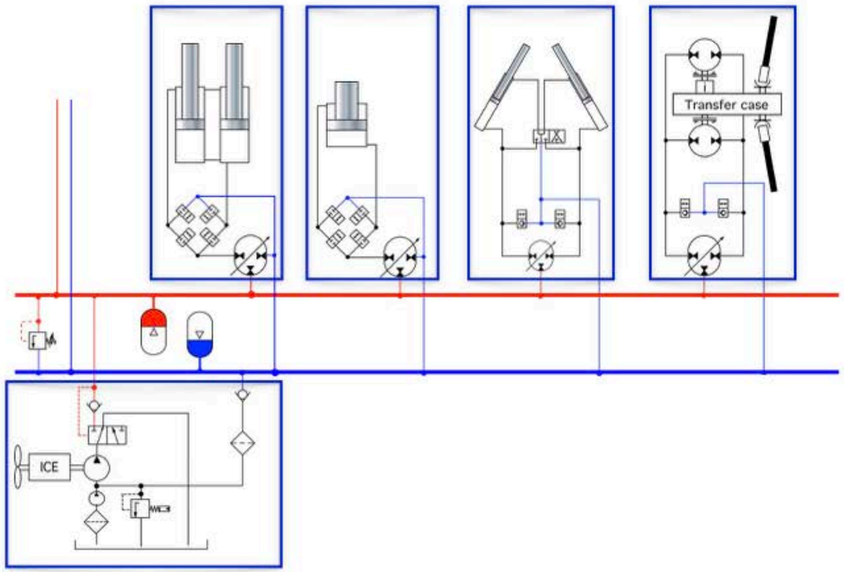
On the other side, there are the various loads. The relative large capacity of the accumulators avoids any issues with load interference or cross-talking.

Essential for this system are the transformers: hydraulic transformers, of course! These transformers are the bridge between the common pressure rail having a certain pressure level, and the loads, also demanding a certain pressure level.

The transformers convert the hydraulic power, that is the product of flow and pressure, to another hydraulic power at a different pressure level, but without any principle losses. The transformers can also amplify pressures. As a result, the pressure level of the main rail can be relatively mild, whereas the loads can still have much higher pressure levels if needed.

Moreover, since the transformers are non-dissipative, the power conversion can go both ways: energy can also be recuperated and stored into the hydraulic accumulators.

CPR-System

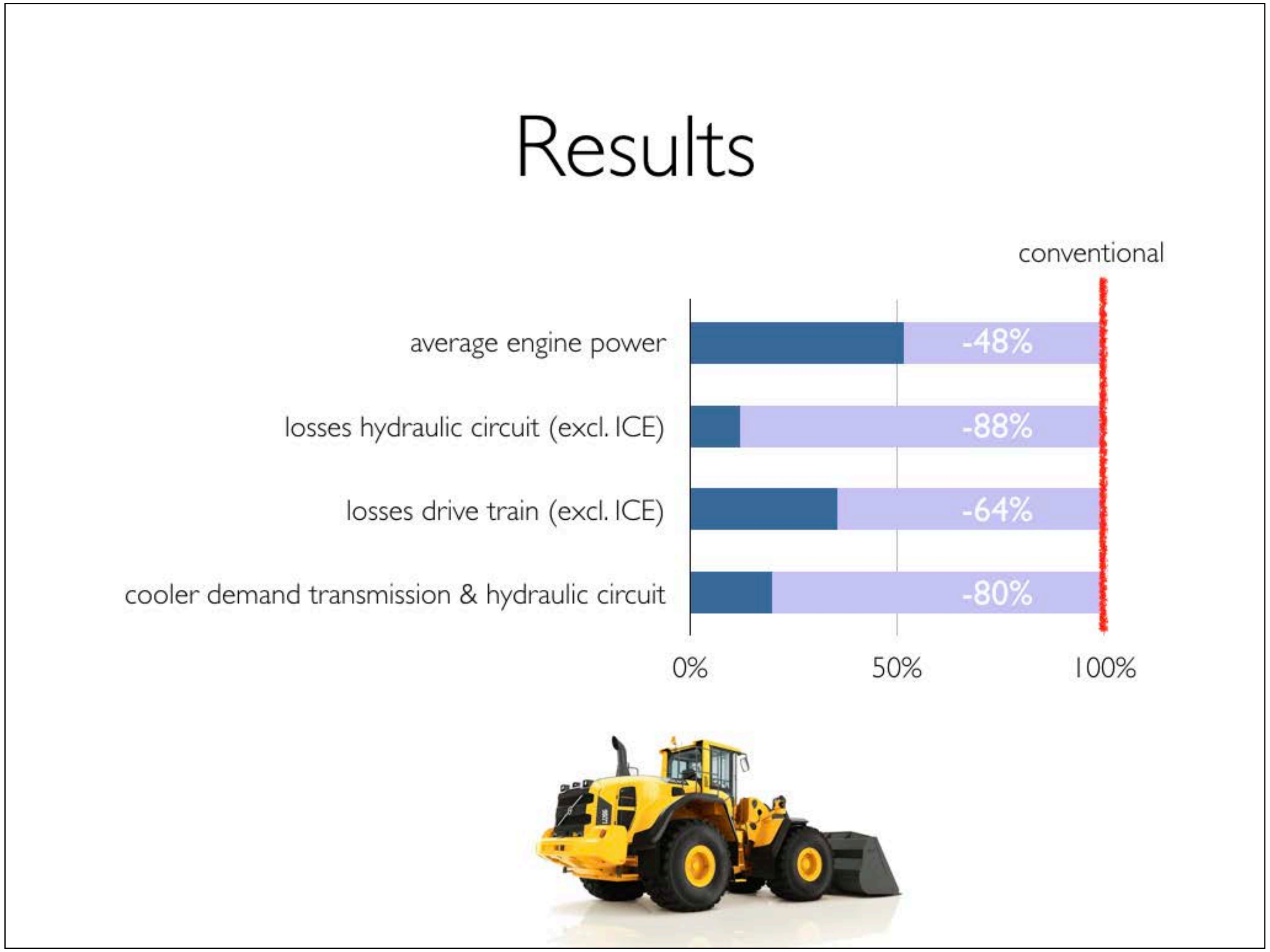


Modules

The CPR-system is a modular system. In stead of having a single, large and complicated system, we now have separated the system in individual modules, on the load side and on the power supply side each having its own control and hydraulic socket.

A few years ago, we had an interesting study, together with VCE: Volvo Construction Equipment. In this study, the CPR-system was applied in one the largest wheel loaders from VCE, and compared to the conventional transmission and hydraulic circuit.

It was only a simulation study. But we used measured component efficiencies as a basis, so we are confident that the simulations are accurate.



These were the results:

- The average engine power has been reduced by more than 50%;
- The losses of the hydraulic implement system have been reduced by almost 90%
- The losses of the drive train have been reduced to about one third, mainly due to the elimination of the torque converter;
- Furthermore, the cooler demands have been reduced by about 80%.

This last result is of great importance since it immediately saves both costs and component space.

Results

50% less fuel

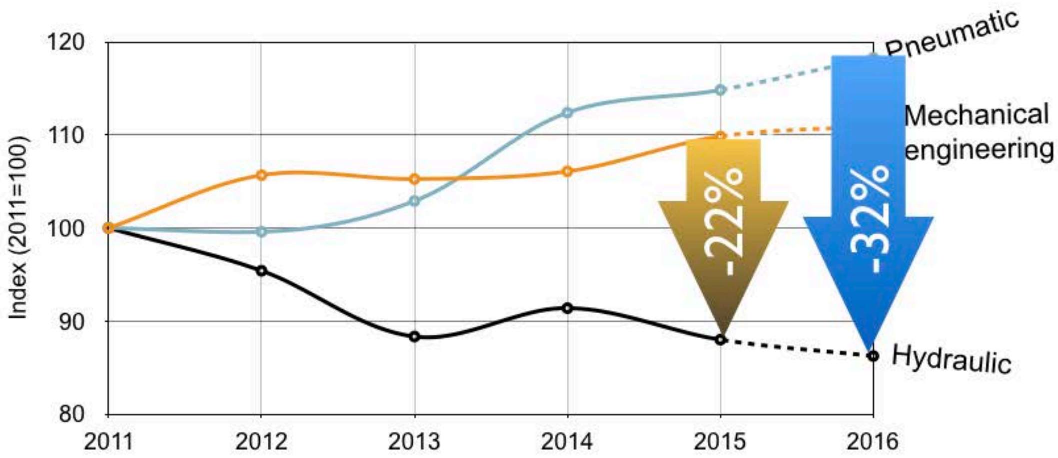
Finally, the CPR-system reduces the fuel consumption by 50%, while maintaining the dynamic behavior and the performance of the machine.

Potential of the hydraulic industry

Now, that I have shown to you, two examples of the via negativa, the question is where this road will lead us to? What potential does the hydraulic industry have?

Recession

- German hydraulic industry:
  - between 2011 and 2015: 22% loss of sales compared to mechanical engineering



Or… should we ask ourselves if there is a potential, at all? The latest economic figures clearly show that the hydraulic industry is in a recession.

These are the numbers from the German industry. After the economic crisis of 2009 and 2010, the mechanical engineering sector is recovering, slow but steady.

The pneumatic industry is even doing better, having an expected growth of close to 20% since 2011.

But the trouble kid is the hydraulic industry. Compared to the general mechanical engineering industry, the hydraulic industry has lost 22% in 4 years.

And, compared to the pneumatic industry, the hydraulic industry is expected to loose almost a third of the sales.

Recession

- German hydraulic industry:
  - between 2011 and 2015: 22% loss of sales compared to mechanical engineering
- US Hydraulic industry:
  - 2015 vs 2014: 11% loss of sales
  - first quarter 2016 compared to the same quarter in 2015: 10.7% loss of sales

The numbers from the NFPA are not much better:

In 2015, the hydraulic industry lost 11% of the sales volume compared to the year before;
A similar downfall has occurred in the first quarter of this year.

But I have a strong confidence in the hydraulic industry. The foundation of the hydraulic industry is rock solid.

I have to admit, given the current situation, it’s a small rock, and also rather isolated.
But, I’m convinced that the hydraulic industry is strongly undervalued. There is a hidden, much larger potential.

This is possible!

- Higher component and system efficiency
- Cost reduction
- Modular systems
- Energy recuperation and power management
- Dynamic, efficient, compact, economic

And these are the possibilities:

- The efficiency of pumps and motors can be increased to 98%. The system losses can be reduced by 50%;
- These improvements can even be combined with strong cost reductions of both components and systems;
- An important step will be the introduction of modular systems, similar to the way the electric grid is organized;
- These systems will allow energy recuperation and power management;
- The future of hydraulic systems will be dynamic, efficient, compact and highly competitive.

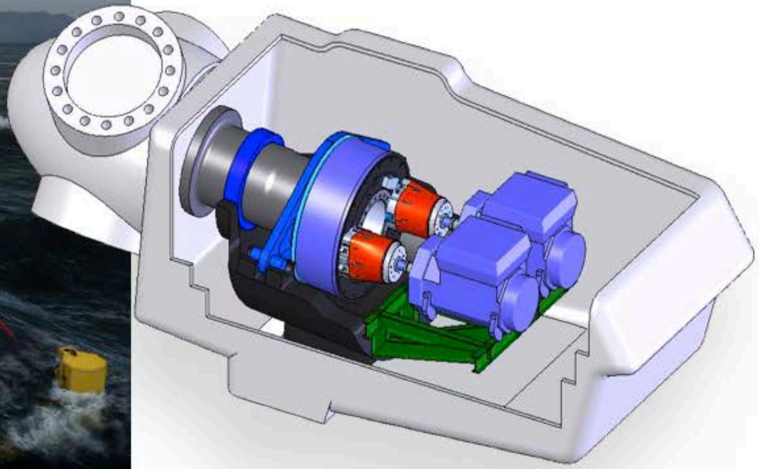
These opportunities allow us to create much better machines: stronger, reliable and much more flexible.

increased productivity

Liebherr winch drive

We will enable our customers to increase their productivity.

competitive wind energy

Mitsubishi Sea Angel

Wind energy will become competitive.

hydraulic hybrids 2.0

Parker RunWise

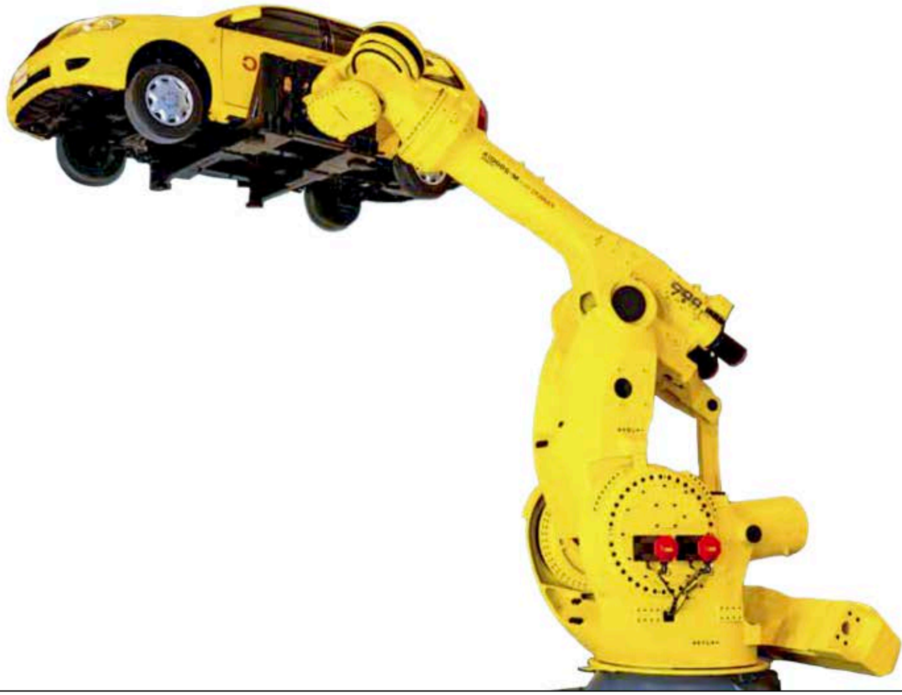
Hydraulic hybrid systems will finally get an update, which will create a real breakthrough for these systems in the market.

efficient & strong machines

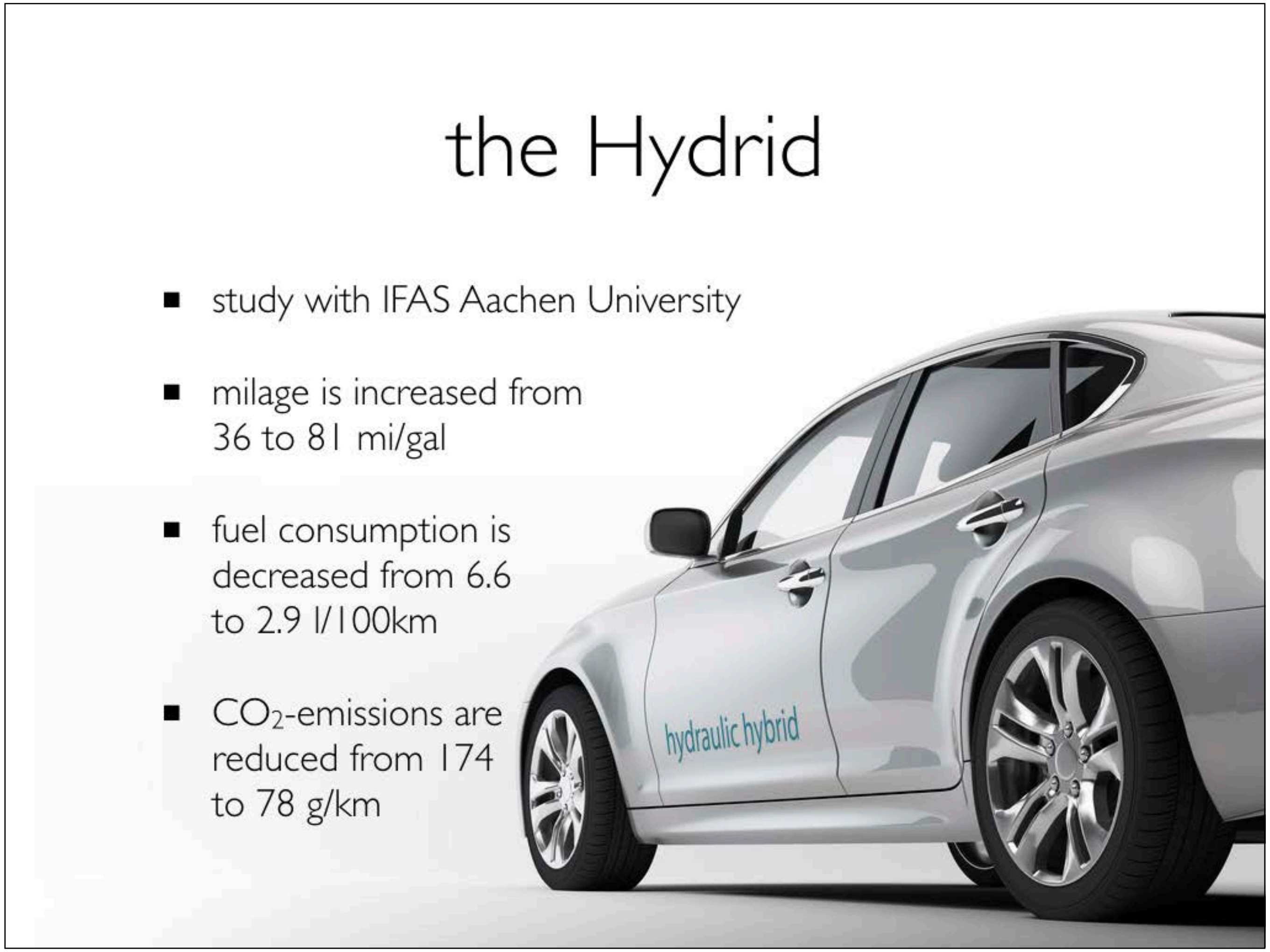
Claas Harvester

Machines will become much more efficient, and the power which was earlier converted into heat, can now be used to make the machines even stronger.

stronger robots



hydraulic systems don't suffer from overheating, and are a much better solution for creating strong robots.



Finally, this is my goal: to create a ‘Hydrid’:

A series hydraulic hybrid transmission for passenger cars and other vehicles.

A few years ago, we performed a study together with the IFAS institute from Aachen University. The study showed that the milage of a mid-sized vehicle can be more than doubled; Which means a reduction of the fuel consumption and the CO2-emissions, of 55%

The pump and motor market is small
world wide about 7 billion Euro
The electric motor and generator market is 16 times bigger;
And the gear transmission market 23 times! Off these 160 billion, 120 billion is for automotive transmissions.

I often hear that the hydraulic industry needs to compete with the electric industry. I disagree with that. I believe that we can't compete with electric solutions, at least not for power levels below 1 kW.

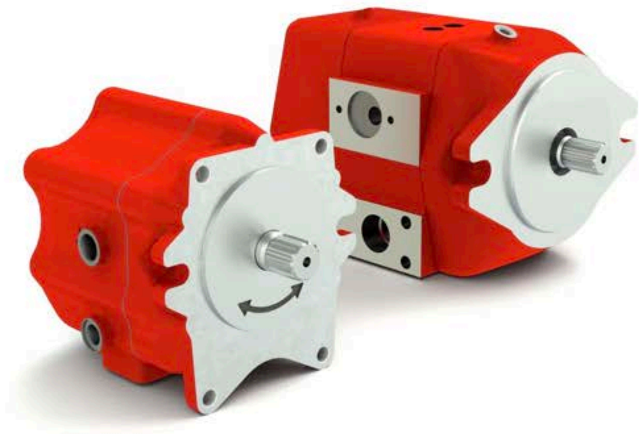
Instead, the gear transmission market should be our target. Now that we know that hydraulic pumps and motors can have an efficiency of 98%, the most important hurdle is already taken. Hydraulic transmissions are much more flexible than mechanical transmissions. They can offer unparalleled opportunities for dynamic control, power management and energy recuperation.

Priorities
(what is really needed?)

And these, ladies and gentleman of the FPIRC and DSCC, these are the priorities for the coming decades. This is where I need your help:

R&D priorities

- better hydrostatic principle

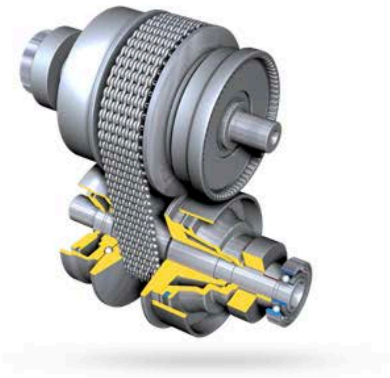


First of all we will need much better, cheaper and more efficient hydrostatic principles. Our floating cup pumps and motors will soon be introduced to the market. But I'm certain that we will need more of such designs and design principles.

R&D priorities

- better hydrostatic principle
- hydraulic transformers

mechanical transformer



Secondly we desperately need hydraulic transformers.

We already have CVT's, mechanical transformers…

R&D priorities

- better hydrostatic principle
- hydraulic transformers

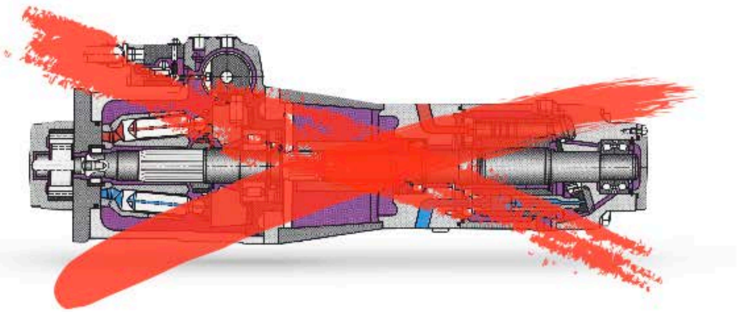
electric transformer

… and electric transformers…

R&D priorities

- better hydrostatic principle
- hydraulic transformers

hydraulic transformer



But we don't have a solution for the hydraulic transformer; at least not an efficient and effective design.

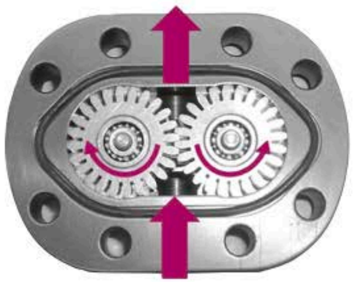
R&D priorities

- better hydrostatic principle
- hydraulic transformers

And I have to admit: we have not yet succeeded in developing a market ready solution as well. There is still a lot of work to done!

R&D priorities

- better hydrostatic principle
- hydraulic transformers
- better & less expensive sensors



A third priority would be the development of small, inexpensive sensors, which don't create high energy losses in the system. We especially need better solutions for flow measurement.

R&D priorities

- better hydrostatic principle
- hydraulic transformers
- better & less expensive sensors
- **new control solutions!**

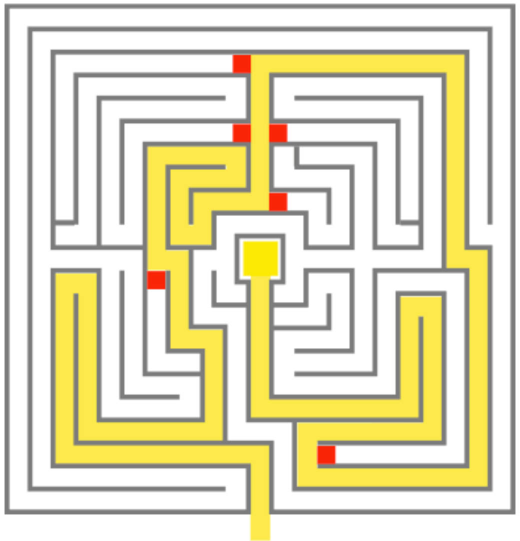
Finally: we need new control solutions. I need hydraulic engineers who have an understanding of Bode plots, Nyquist diagrams and even of Lyapunov instabilities. And I need control engineers who have detailed knowledge of hydraulic systems and components.

the Via Negativa

Dear colleagues, to summarize:

The via negativa

- the maze



I hope that you will be successful on the 'via negativa' and that you won't get lost in the maze.

The via negativa

- the maze
- innovation ≠ simulation

Simulations will help you to find your way, but simulations can also be misleading and stop you from innovating.

The via negativa

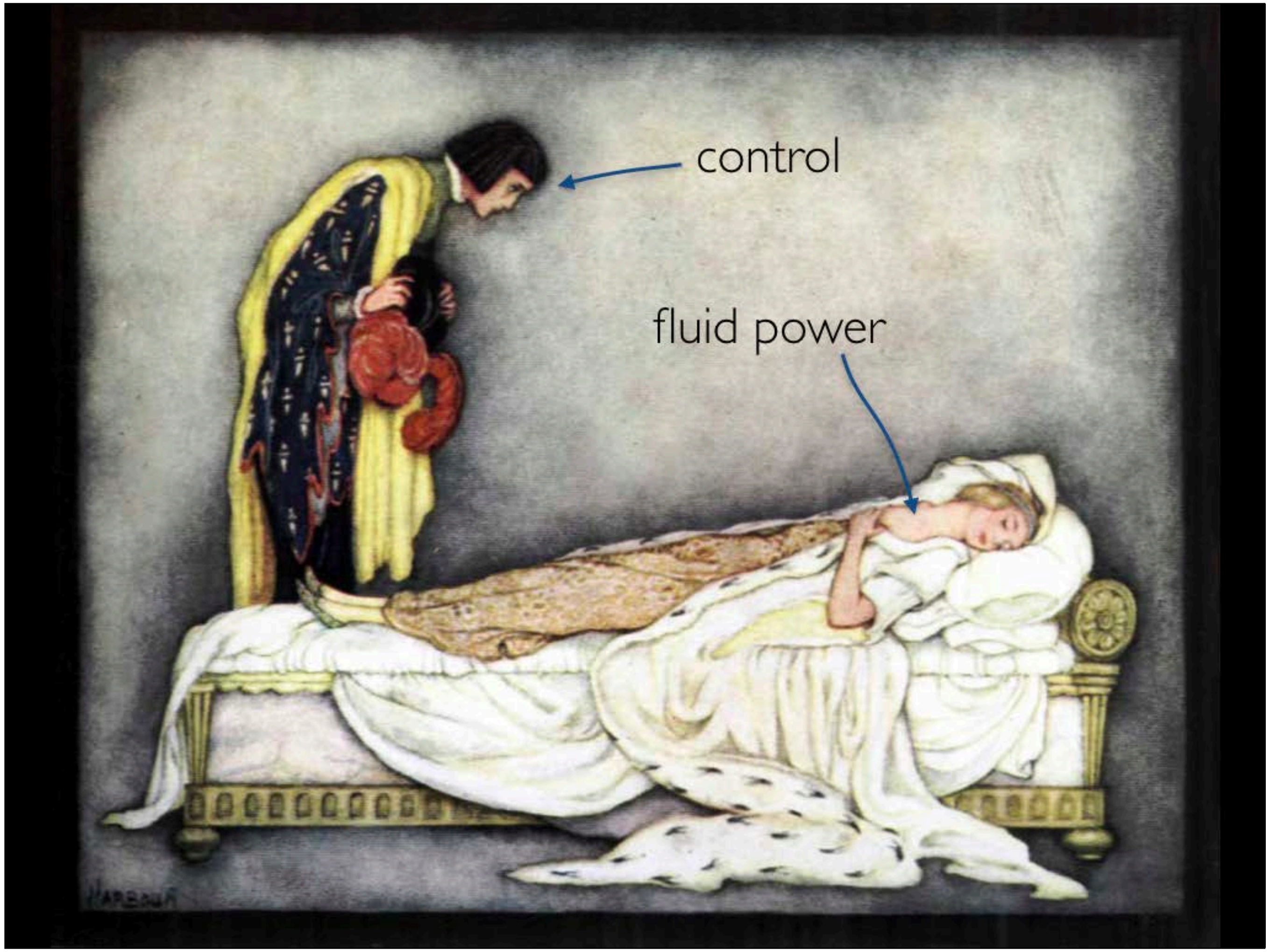
- the maze
- innovation ≠ simulation
- innovation ≠ creativity

It is also a misconception that innovation is the same as creativity. What is needed is a combination of creativity, skills, knowledge and talent.

The via negativa

- the maze
- innovation ≠ simulation
- innovation ≠ creativity
- R&D-priorities and market potential

But with these simple ingredients, the hydraulic industry will be able to reinvent itself.

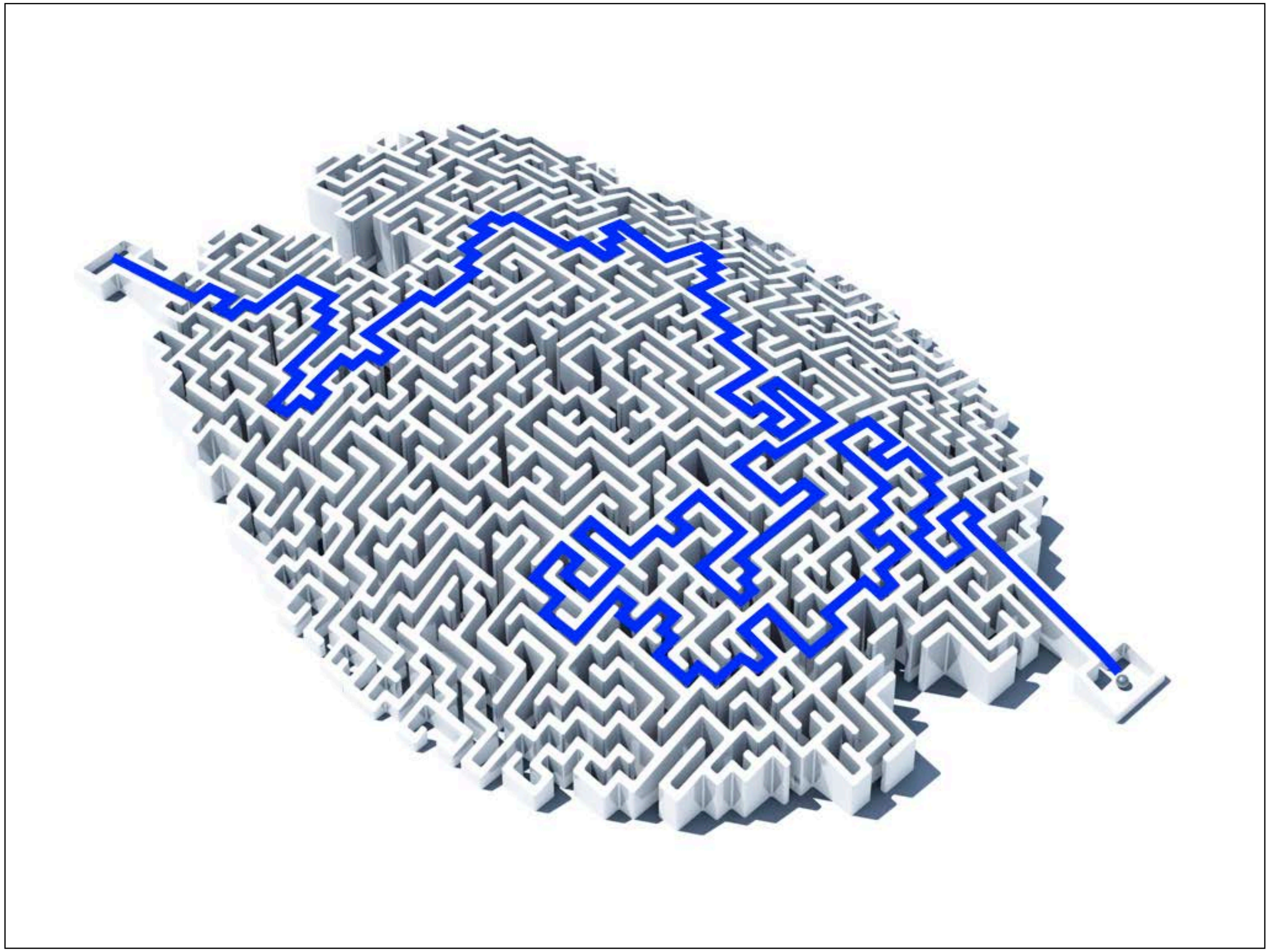


Ladies and gentleman: the fluid power industry is a sleepy beauty with an enormous potential.

What we need is the prince on the white horse who will wake her up with a kiss. And here you are, in one room, sitting together: the beauty and the prince. What an opportunity! I hope that this will work, and that, together, you will find new and better solutions.

finding the right solution

Finding the right solution, finding your way through the labyrinth. I can’t help it. It ain’t easy. Life can be a hassle, and quite demanding.



Everyday you have to make decisions, not just arbitrary, but the right decisions. It already starts in the morning when you have to decide what to wear…

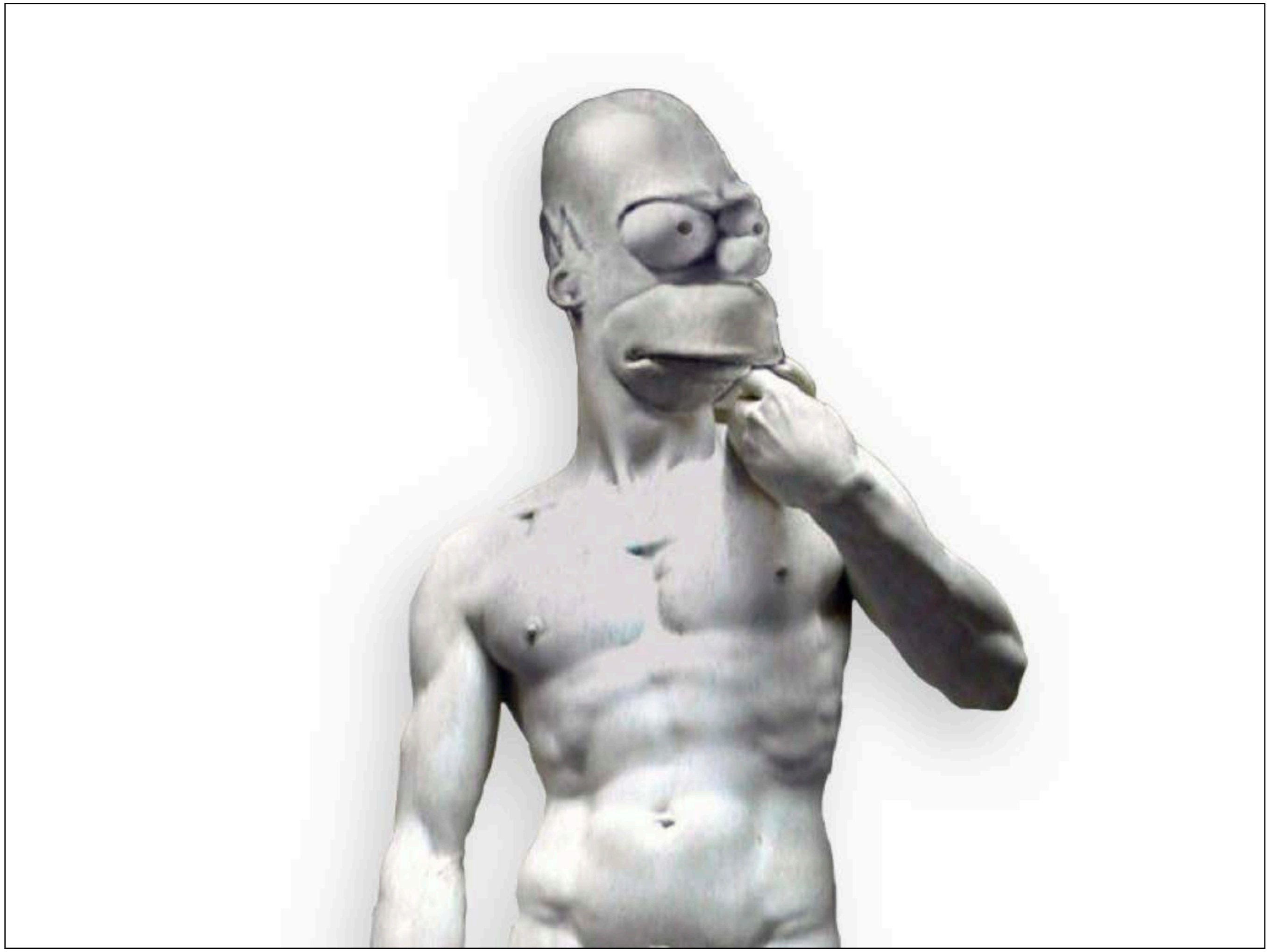
Michelangelo Pistoletto, Venus of the Rags, 1967

…like Michelangelo Pistoletto, the contemporary Italian artist, has brilliantly shown in this artwork.

In the year 1501, another Italian artist, Michelangelo di Ludovico Buonarroti Simoni, was asked to make a statue of the biblical David, as a symbol of Florentine freedom. Michelangelo was only 26 years old when he started to work on this challenging new task.

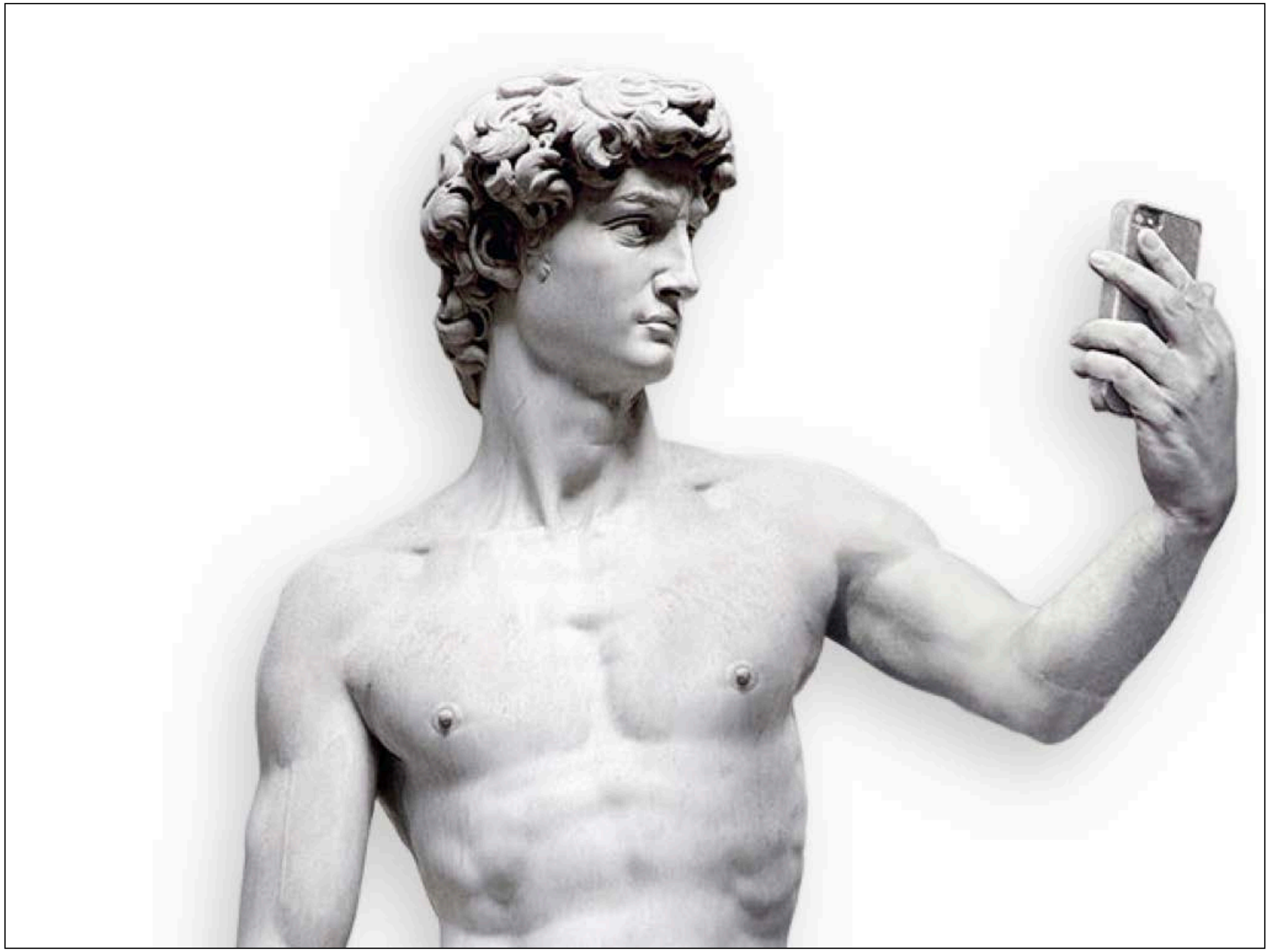
Let this be a message for all of you: don't you think you are still too young to create something of importance.

There Michelangelo stood, in front of this enormous block of precious Carrara marble. He could have carved anything out of this, but his ambition was to make something new, something spectacular. And this…



…no…

… this…no… ☛



…no, that is maybe very creative, but most definitely also wrong…

…this, this was the result. It was immediately recognized and admired as a miracle, the largest and most grand of the ancient statues.

Even the pope came from Rome, to see this miraculous piece of art. "How did you manage to create David, the masterpiece of masterpieces?" the Pope asked.

Michelangelo answered:

I simply removed everything that wasn't David

Michelangelo di Lodovico Buonarroti Simoni

"I simply removed everything that wasn't David"

Via Negativa

The Via negativa.