Challenges and Opportunities for Fluid Power?

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Content

1. Opportunities for new system architectures

2. Opportunities for new directions in pump design

State of the Art in Fluid Power

Hydraulic resistances used for motion control

Low efficien…

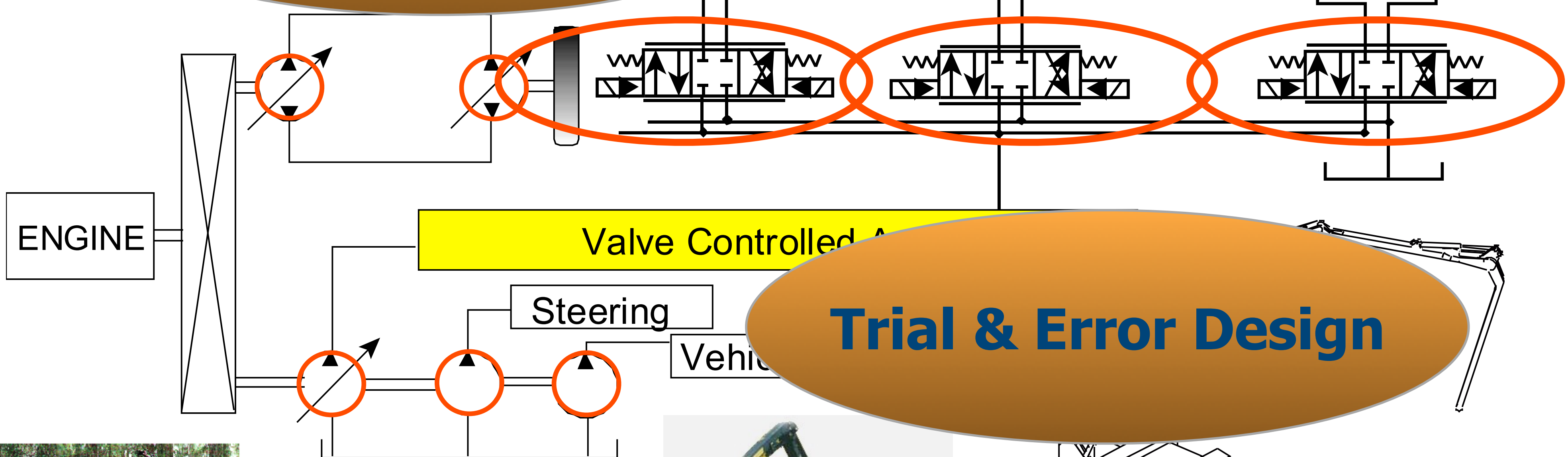
Huma… …ent

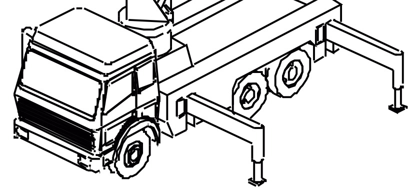
33% energy wasted

15% energy wasted

Throttling Valves

Trial & Error Design





Major question to be answered

How much can performance, efficiency, reliability and costs of hydraulic systems be improved through ***new system architectures, more advanced or new components,*** *and* ***new control algorithms?***

Examples from my own research will be provided!

The Maha System Approach

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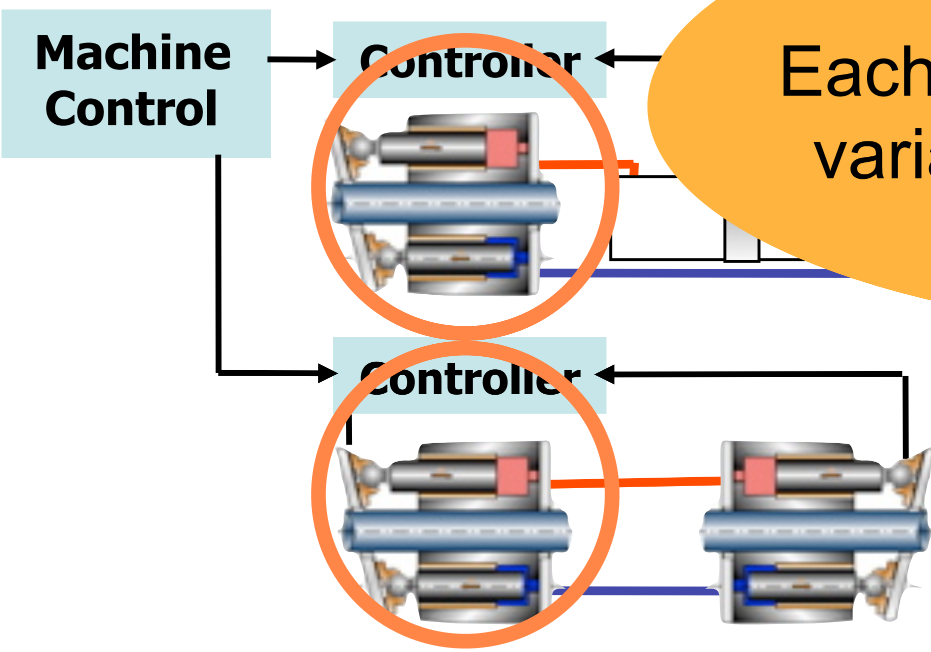
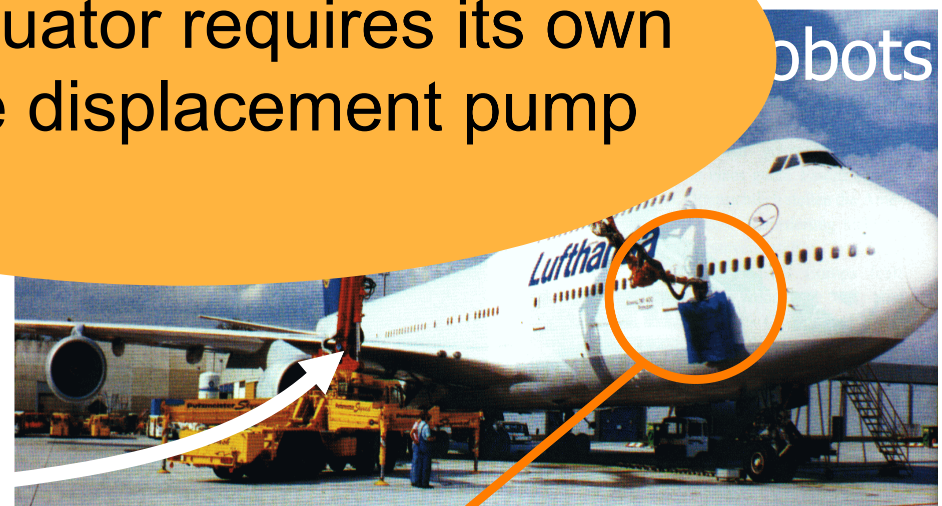
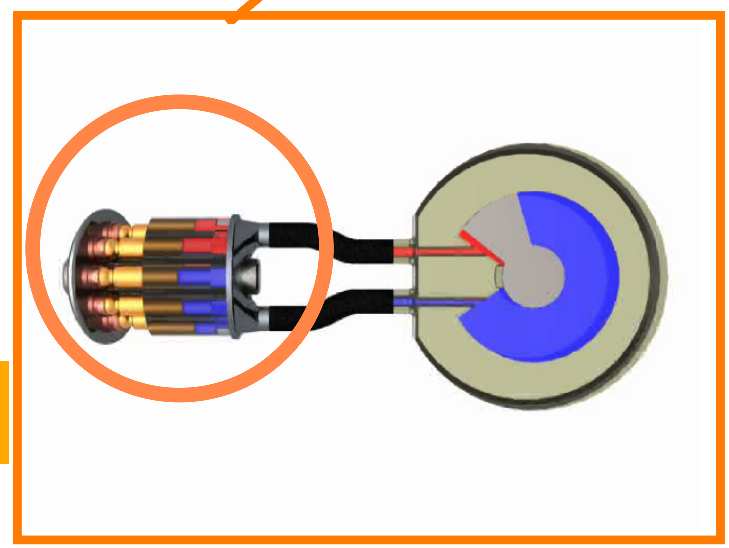
- **Energy Savings by Th Technology**



Each actuator requires its own variable displacement pump





- **energy recovery**

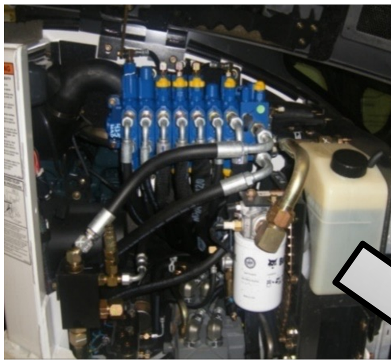
- **no throttling losses**

(DC) Pump controlled actuator

Displacement Control

Example: Displacement Controlled Excavator

LS Hydraulics

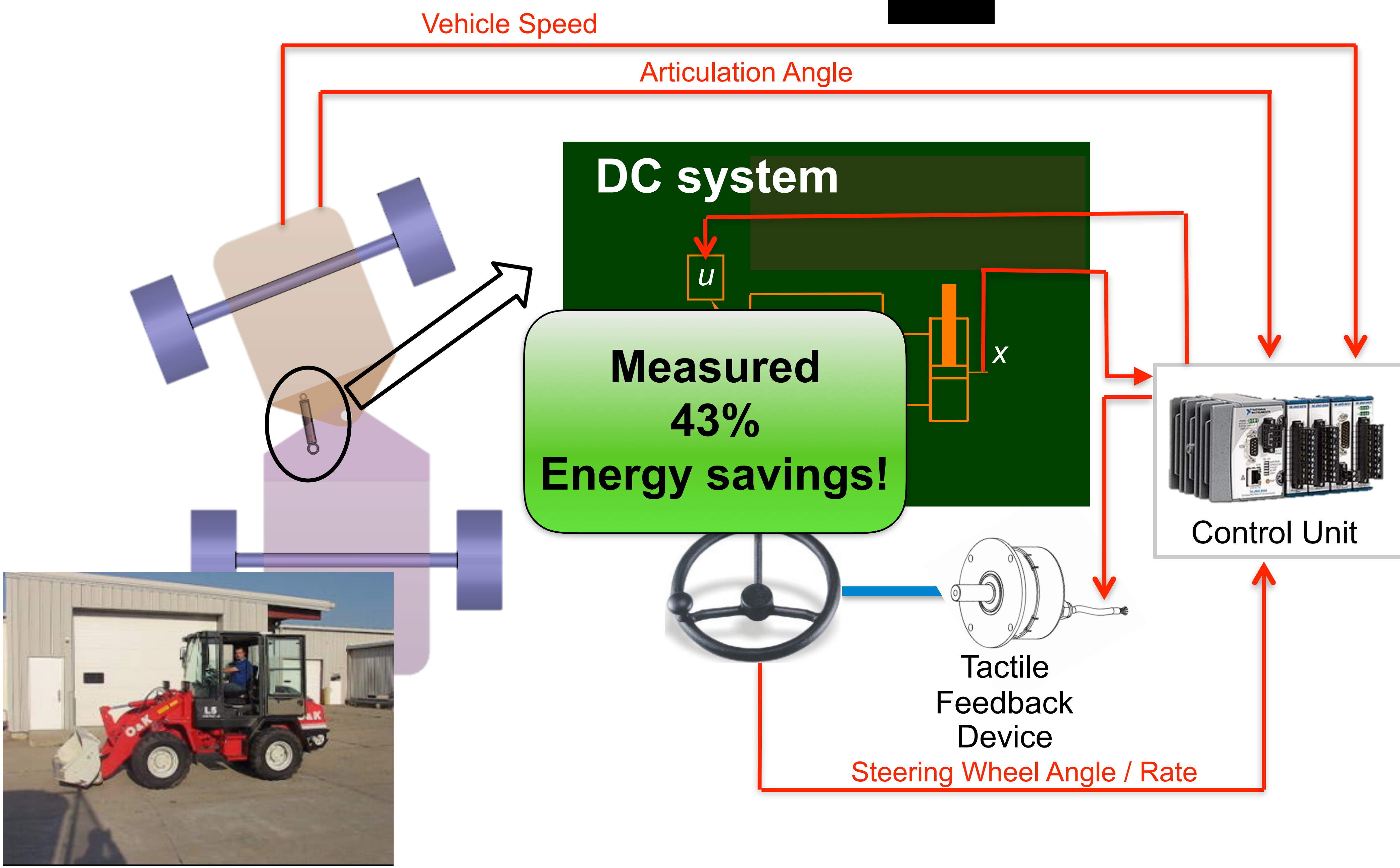


DC Hydraulics

Measurement Results (CAT external)

Parameter	Fuel	Cycle	Productivity	Efficiency
Units	[t]	[s]	[t/h]	[t/l]
Improvement	-40%	-14%	+18.9%	+69.4%

DC Steer by Wire

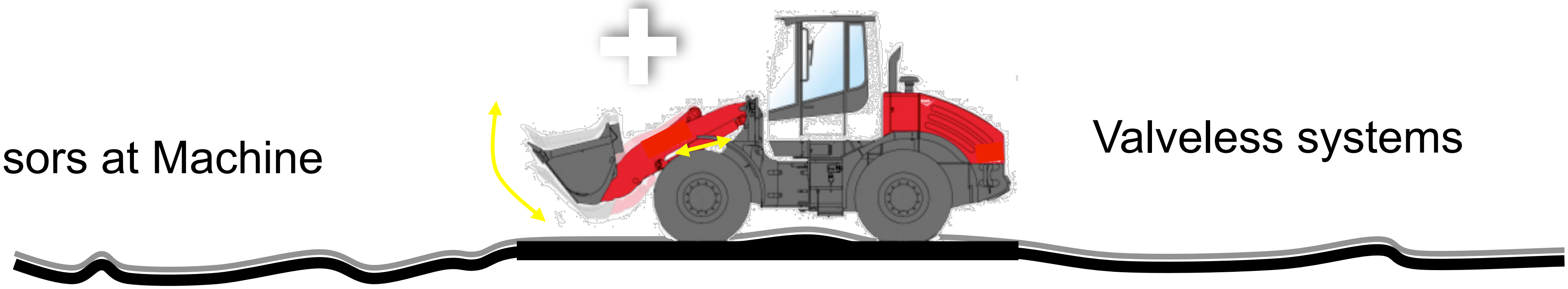


Hydraulic steer by wire system

- **Energy efficient**
- **Variable steering ratio**
- **Variable steering effort**
- **Autonomous operation**

Active oscillation damping

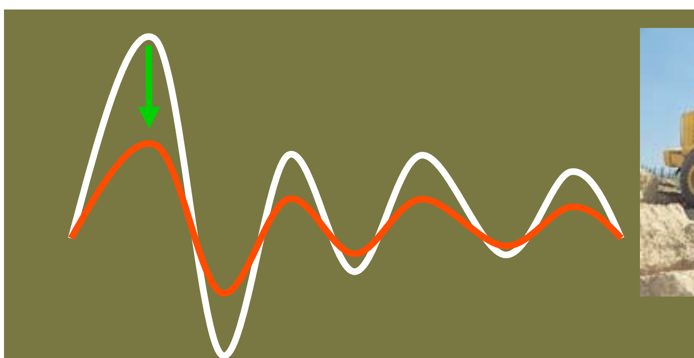
Sensors at Machine



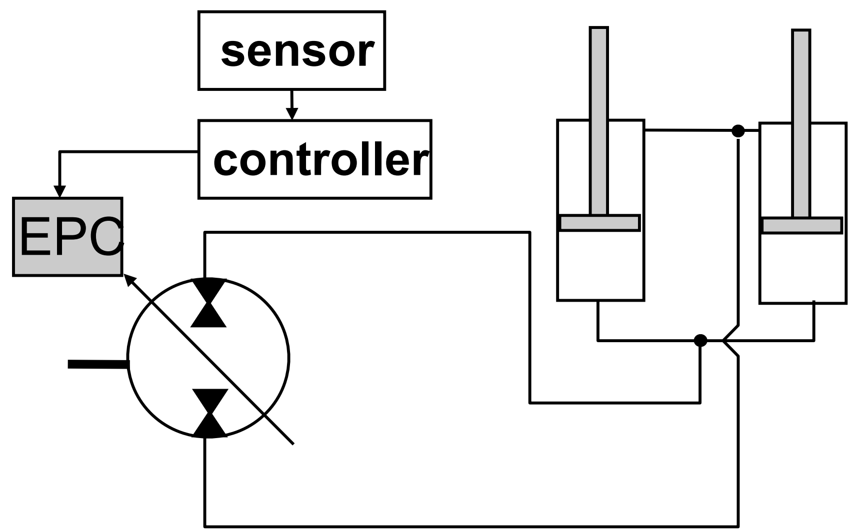
Valveless systems

Active Damping of Boom Structure and Cabin

ACTIVE (VALVELESS)



Improvement of:



- Safety
- Driving velocity
- Operator comfort
- Productivity

DC Hybrids combined with hybrid transmissions

Engine downsizing with hybrids

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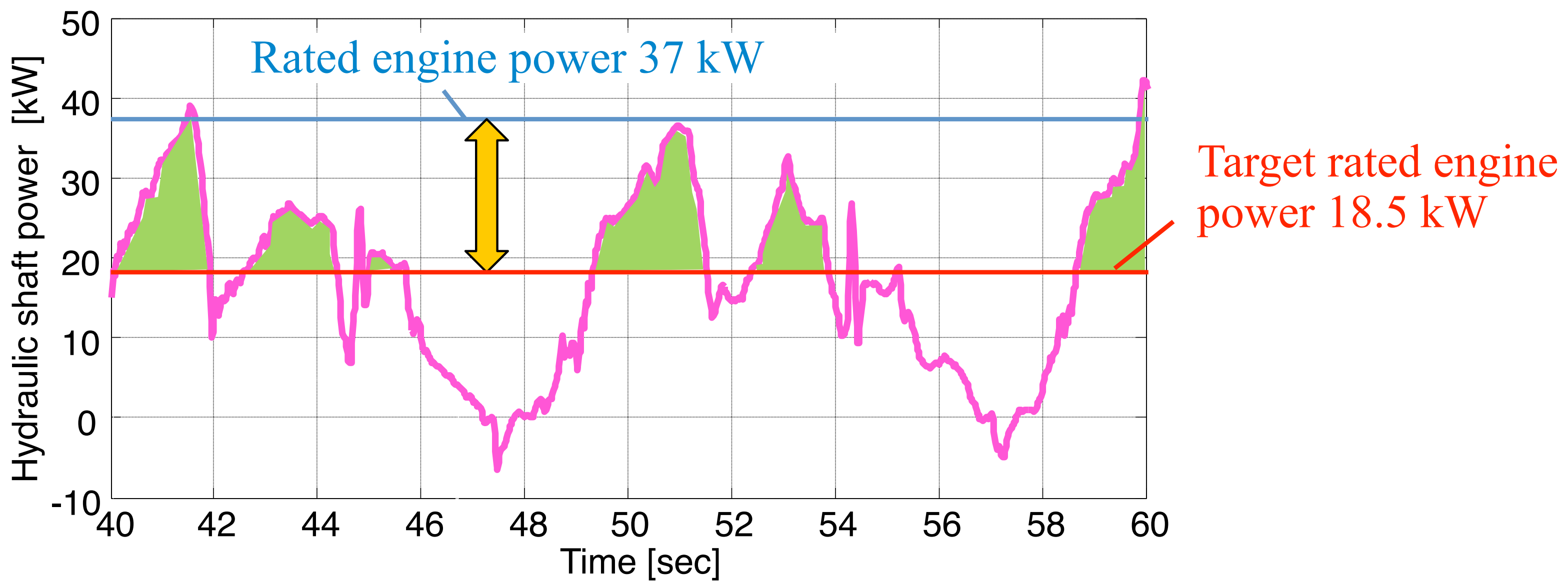
Theoretically the engine power can be reduced to the average cycle power if an energy storage system is added to a system

Example:

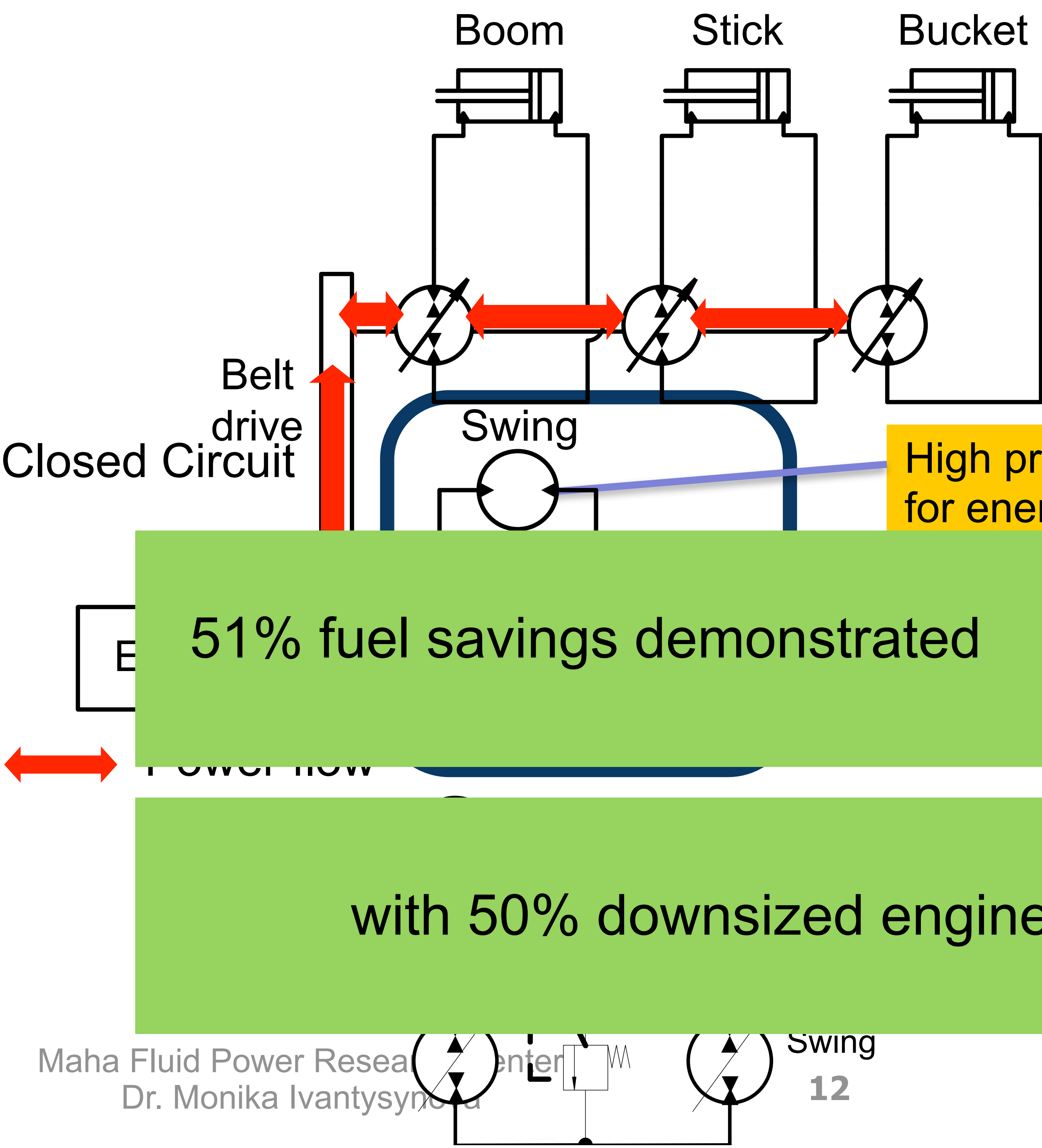
Energy required from energy storage system

Max power required from energy storage system

DC hydraulic system power



Series-Parallel DC Hybrid



Patent filed
(S. No. : 61/453,368)

DC linear actuators

High pressure accumulator
for energy storage

51% fuel savings demonstrated

with 50% downsized engine

Reach Stacker Example

5.1 MJ

of potential energy

1.9 MJ

of kinetic energy

Unloaded

1.7 MJ

of kinetic energy

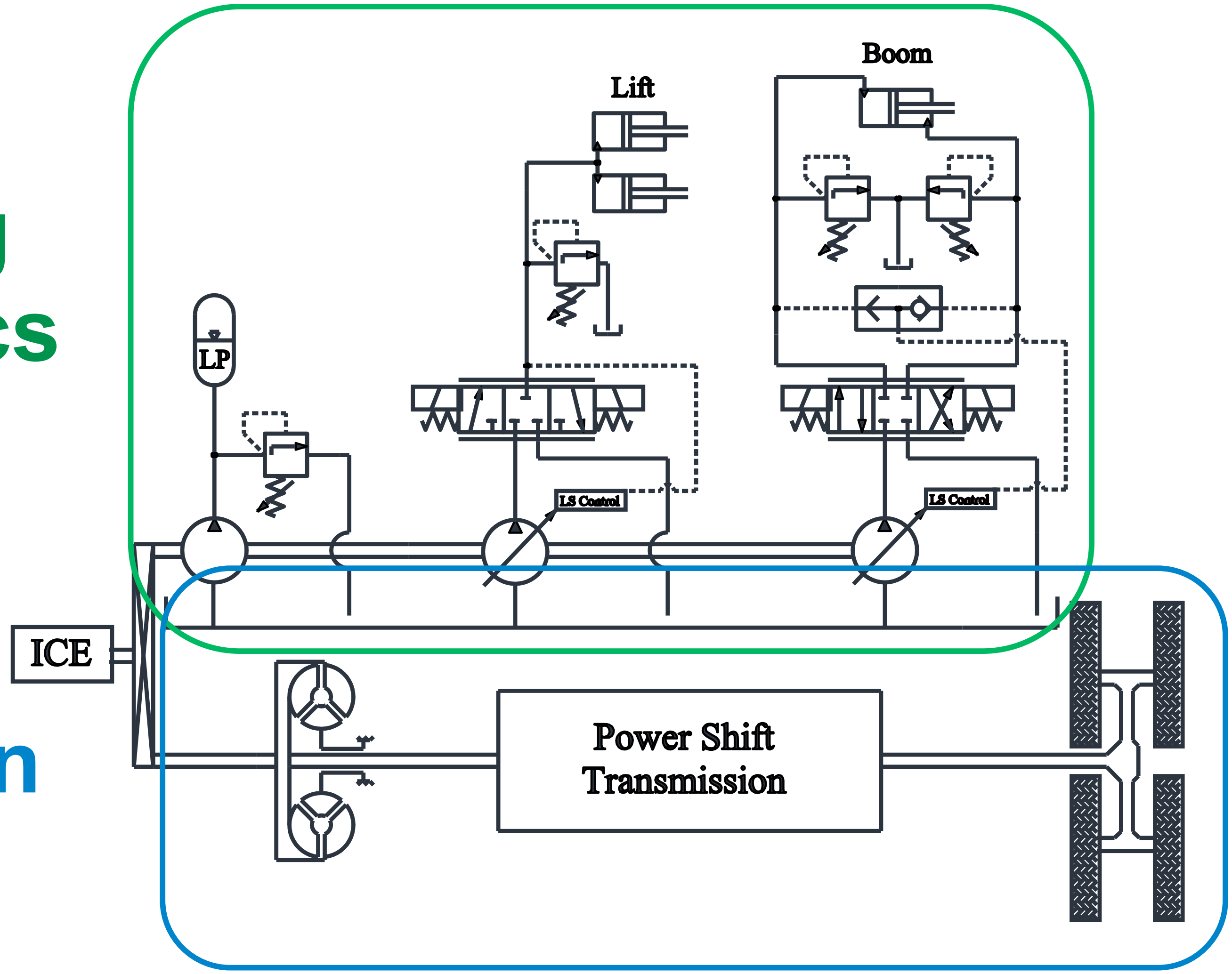
Loaded

Engine:	280 kW
Machine mass:	77 tones
Container mass:	45 tones
Top speed (unloaded):	25 km/h
Top speed (loaded):	19 km/h

Conventional Reach Stacker Architecture

Working Hydraulics

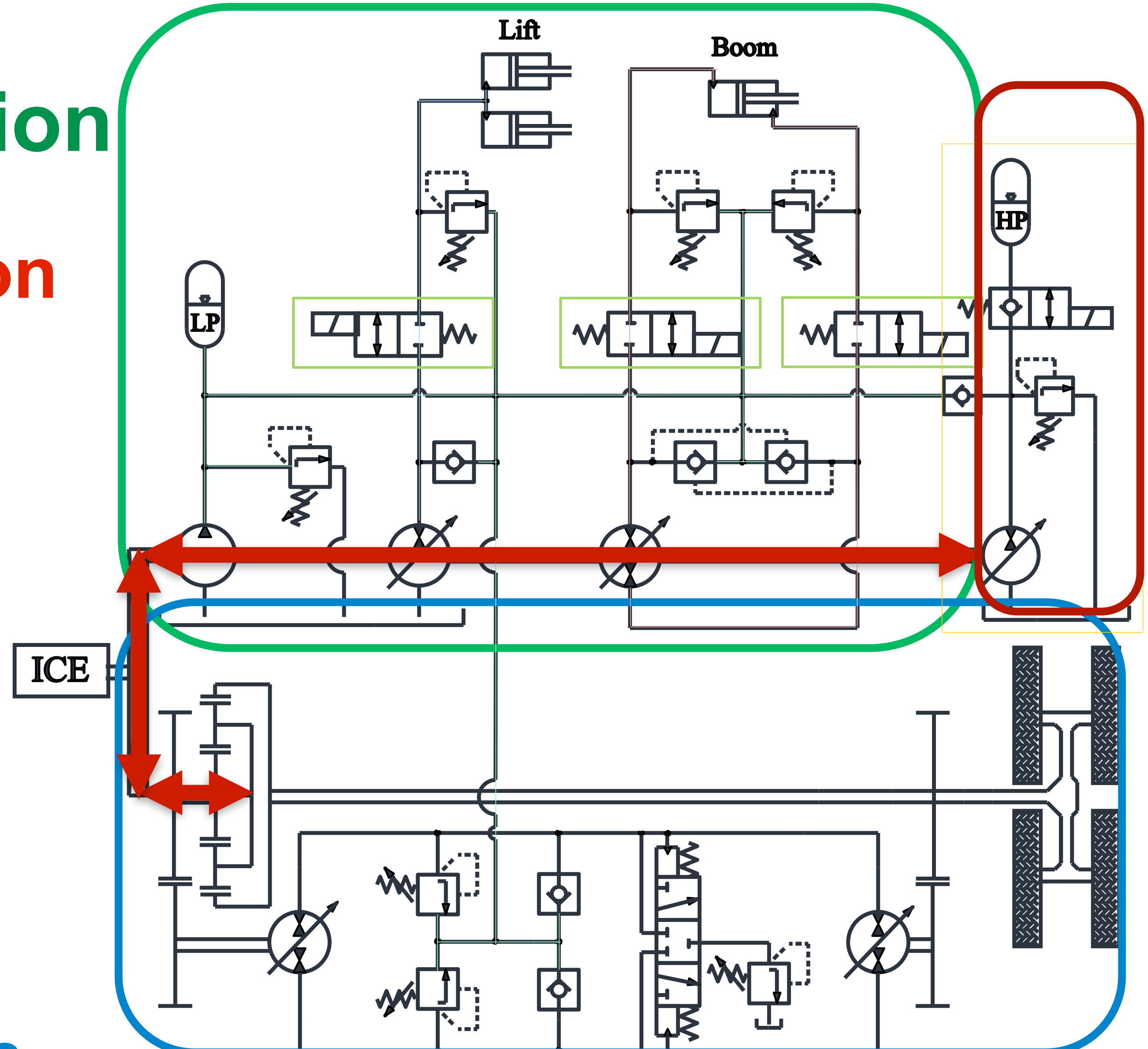
Drivetrain



Reach Stacker Example

DC Actuation

Hybrid configuration with added accumulator and pump/motor unit



Power Split Transmission

Energetic Comparison

Baseline Machine
Modified Machine
% Change

12.3 MJ 9.6 MJ -22.1%		
10.9 MJ 8.1 MJ -25.8%	10.6 MJ 7.7 MJ -27.9%	
9.4 MJ 6.6 MJ -30.1%	8.7 MJ 6.2 MJ -28.7%	7.5 MJ 5.2 MJ -30.8%
7.6 MJ 5.0 MJ -34.4%	7.3 MJ 4.8 MJ -34.3%	6.5 MJ 4.4 MJ -31.6%
6.5 MJ 4.2 MJ -34.8%	6.4 MJ 4.3 MJ -32.7%	6.0 MJ 4.0 MJ -32.9%

Stacking Cycle

8.3 MJ 2.3 MJ -72.9%		
7.4 MJ 2.4 MJ -67.5%	7.4 MJ 2.6 MJ -64.5 %	
7.0 MJ 3.2 MJ -54.0%	6.9 MJ 3.5 MJ -49.9 %	6.4 MJ 3.6 MJ -42.8%
6.6 MJ 4.1 M -3	6.4 M	

Uns

47.9%
Average reduction while unstacking

29.7%
age reduction
ing

38% average reduction in energy consumption

Hybrid transmissions and power trains

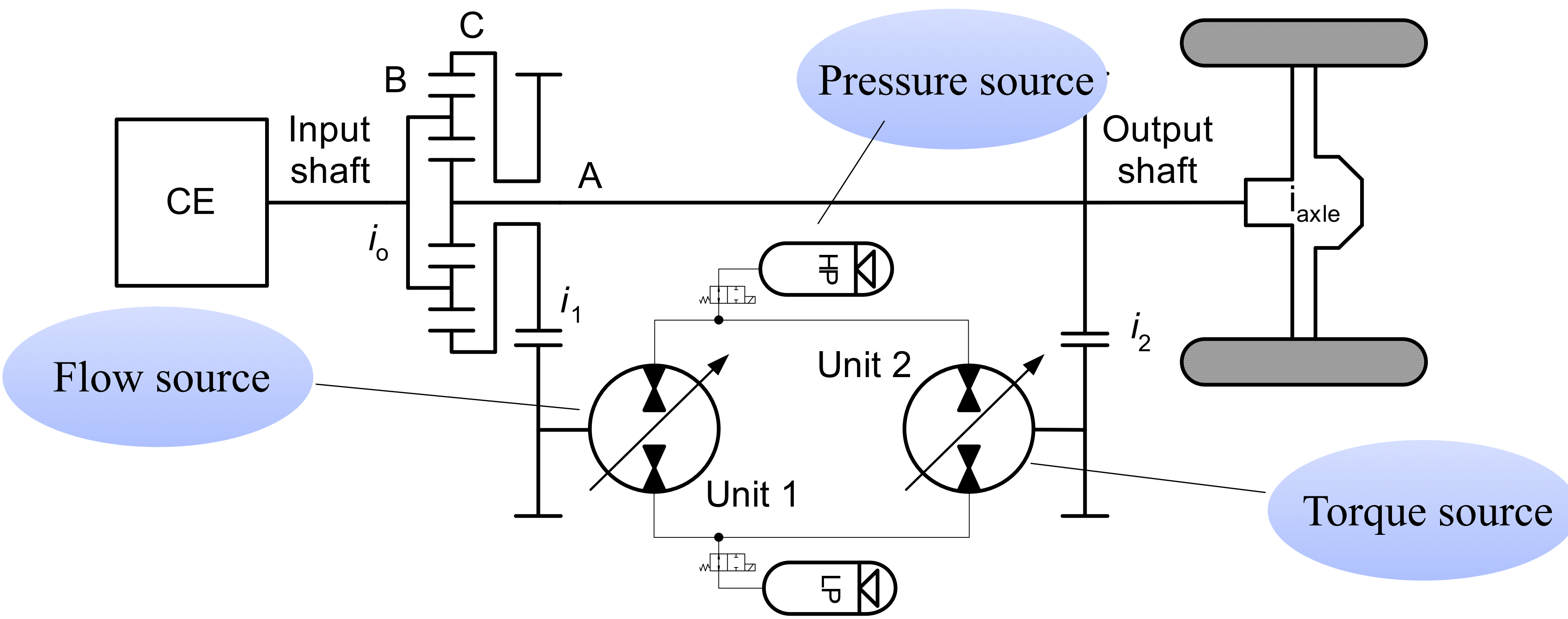
for on road vehicles

Fuel savings through Hybrids

- Regenerative braking
- Engine management
- Efficient transmission concept
- Efficient and light components

Power split transmissions & power split hydraulic hybrid

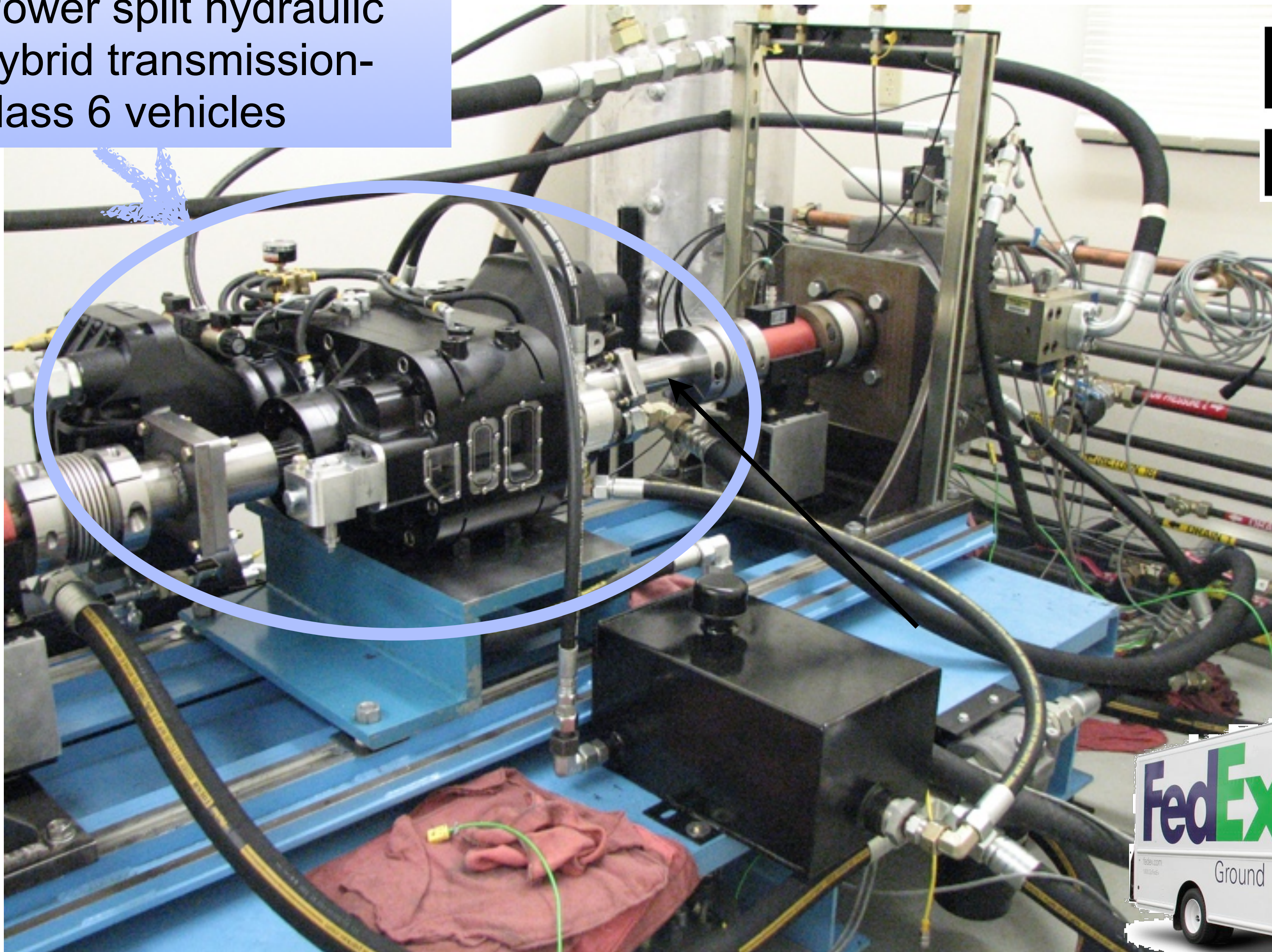
highly efficient power split transmissions replacing power shift and hydrostatic transmissions



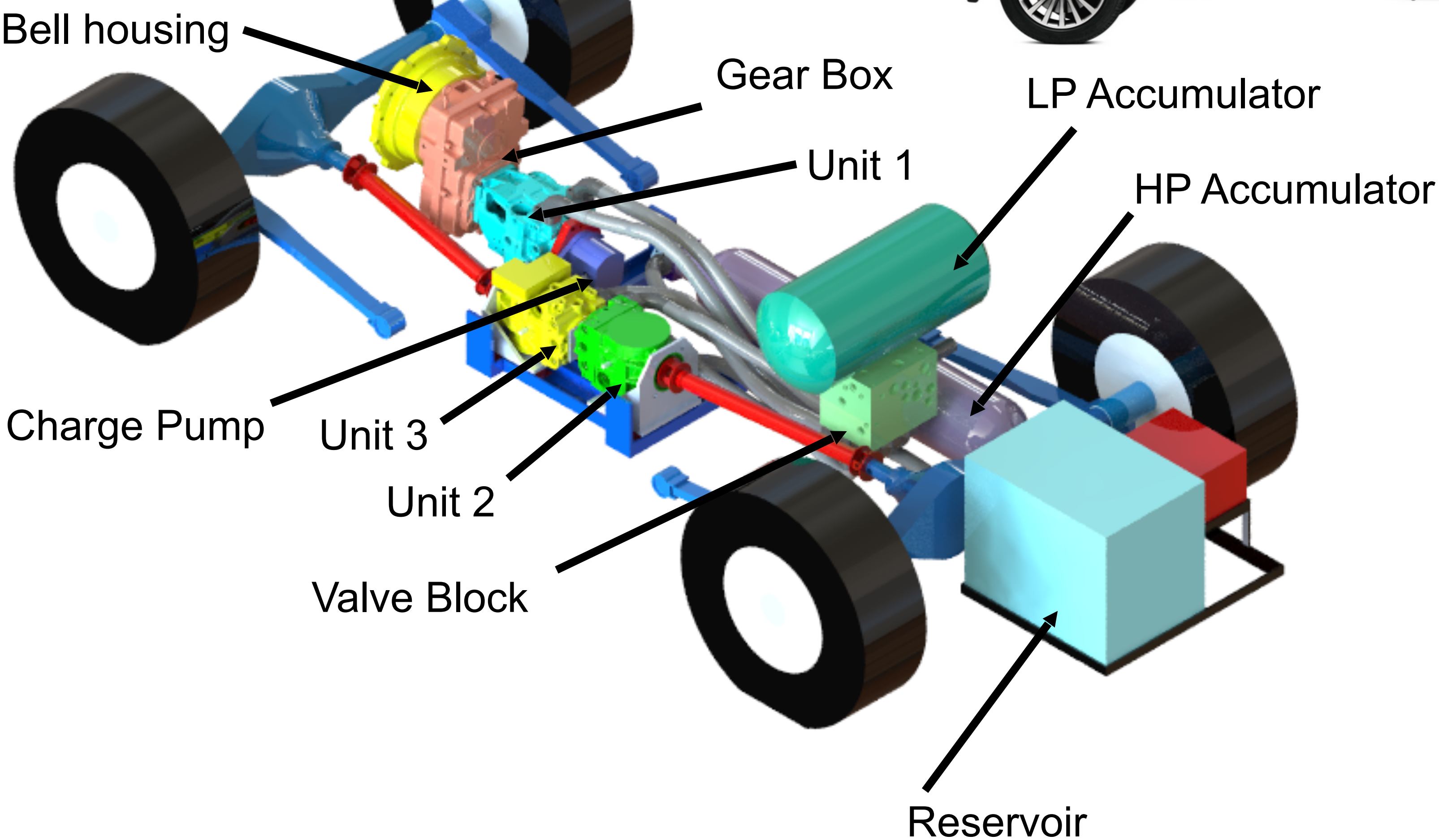
US patent No 8,277,352 issued October 2012 & US patent No 8,454,469 issued June 2013

Hydraulic Hybrid Vehicles

Power split hydraulic hybrid transmission- class 6 vehicles



Maha Hydraulic Hybrid SUV



Maha Hydraulic Hybrid SUV

New design methodology for pumps & motors

The secret of the fluid film

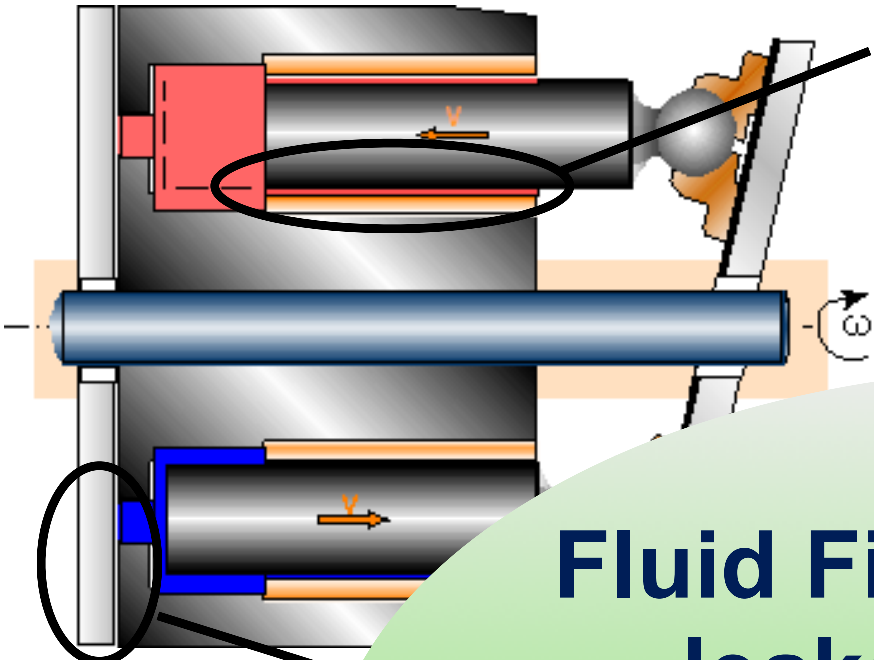
Pump Design Requirements

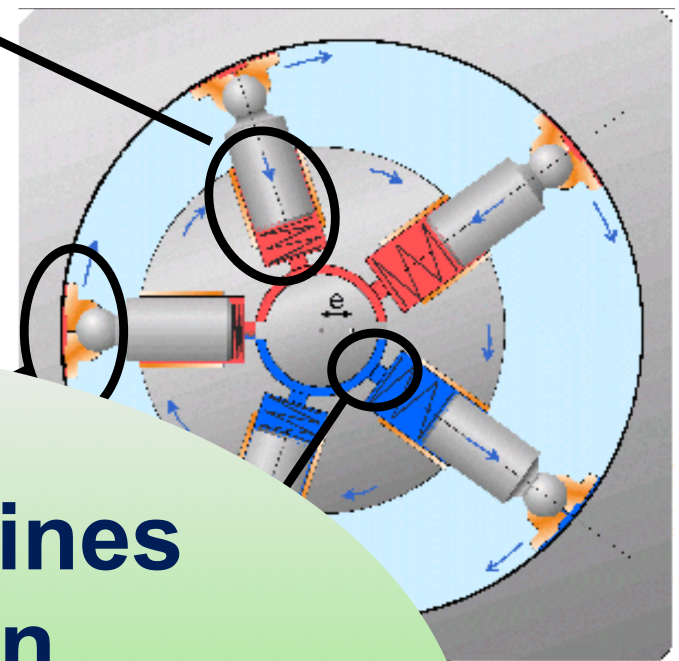
- **Smart Pumps - Advanced Pump Control**
- **High Efficiency**
- **High Power Density**
- **Simple design / low cost**
- **High Reliability**
- **Low Noise Emission**

Innovations in Pump Design

What are the technologies & tools to be applied?

The secret of the fluid film





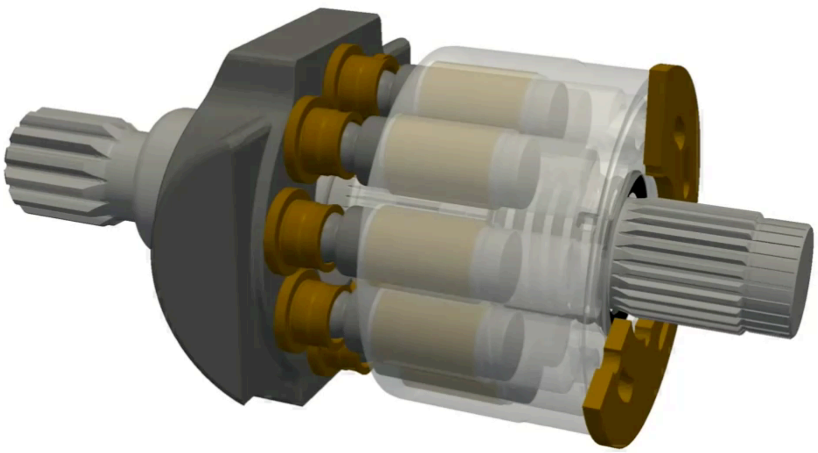
Axial pisto

machine

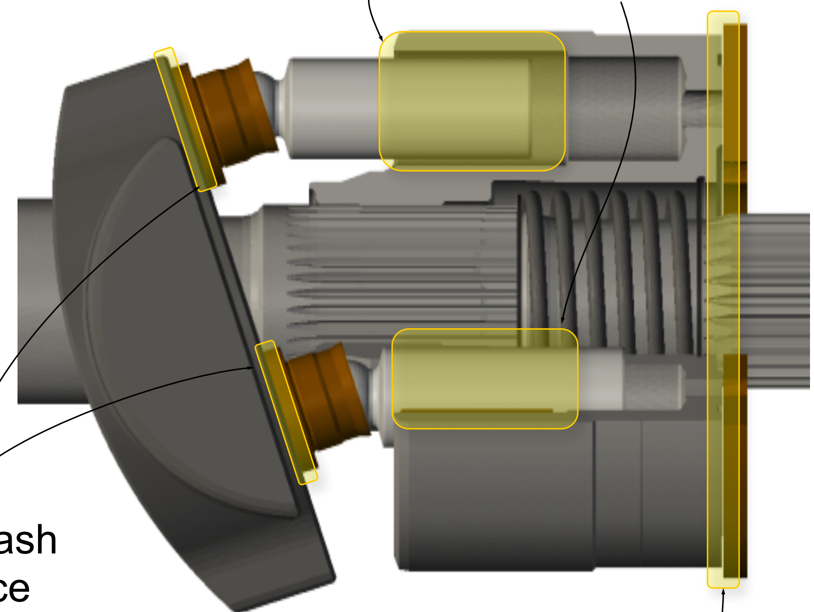
Fluid Film determines
leakage, friction
and load carrying ability
&
is the biggest unknown

How is the fluid film created?

Machine kinematics



Design parameter - clearances



Material properties

Surface finish

and what else plays a role?

Load carrying ability of lubricating film

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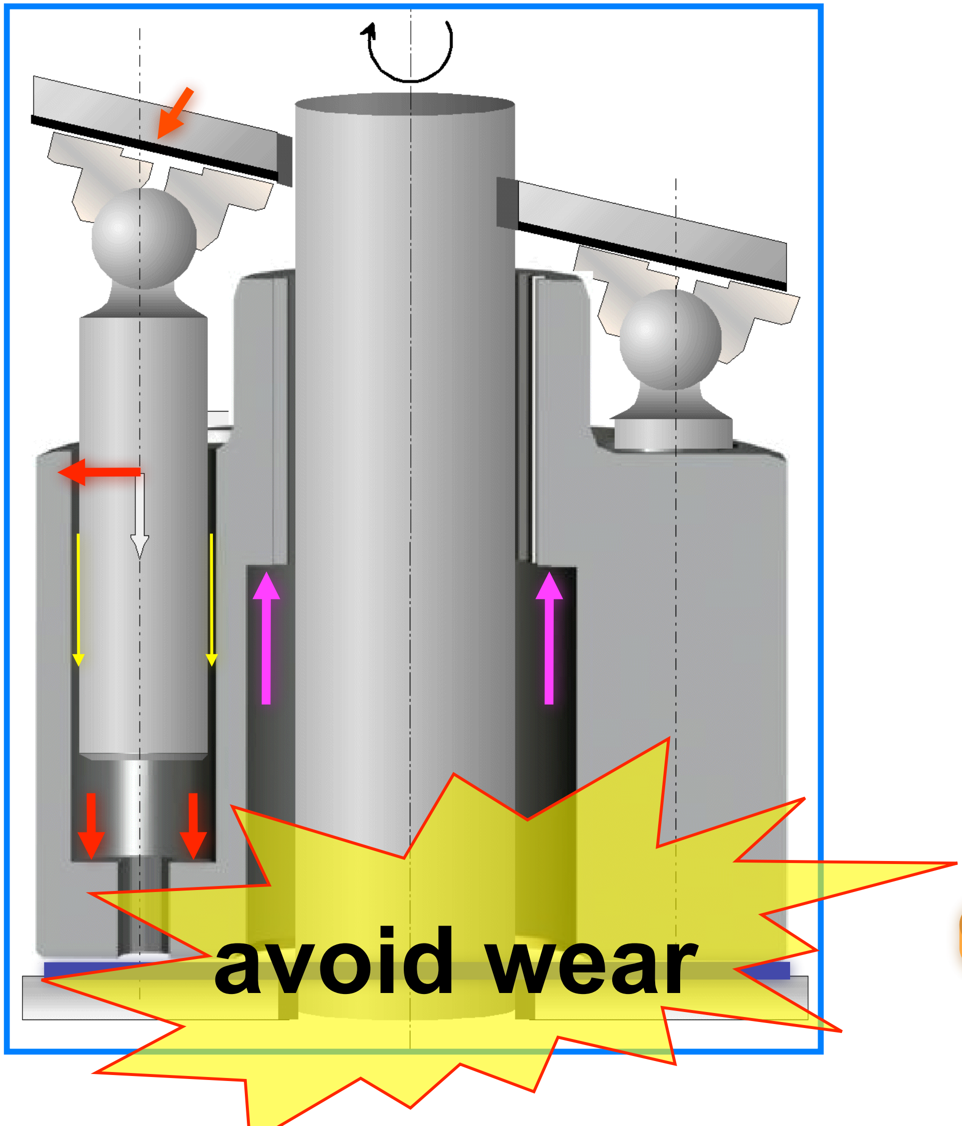
fluid film has to balance external forces

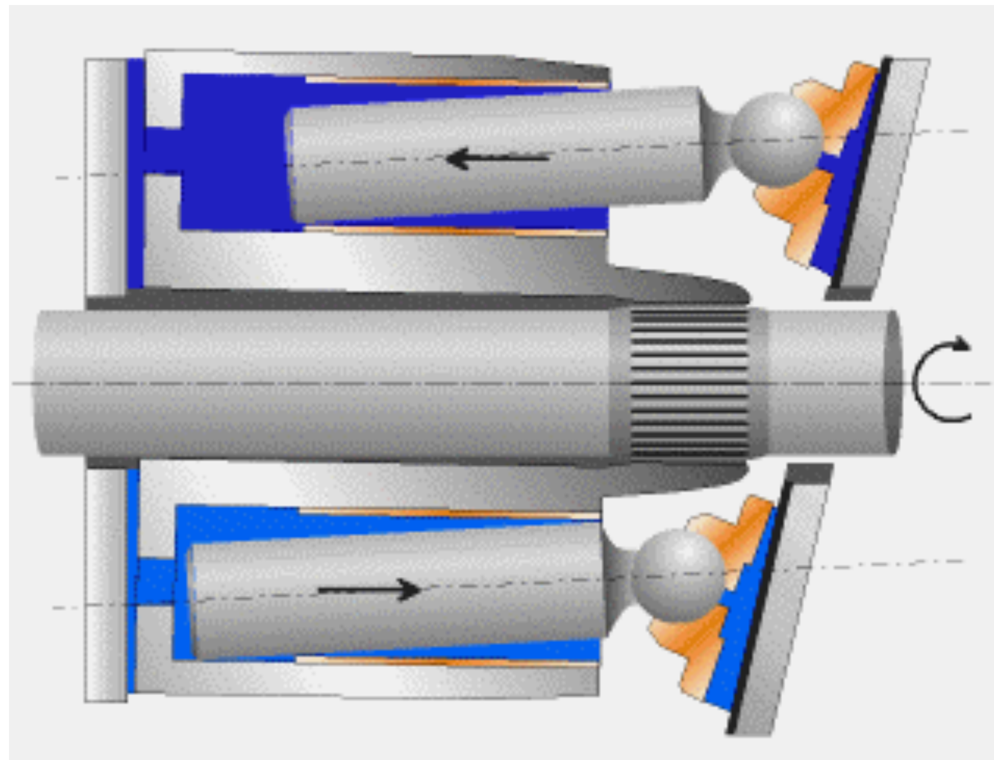


- Pressure force
- Piston friction force
- Spring force
- Centrifugal force & reaction force of swash plate

Balanced by fluid forces

Physical effects to be considered

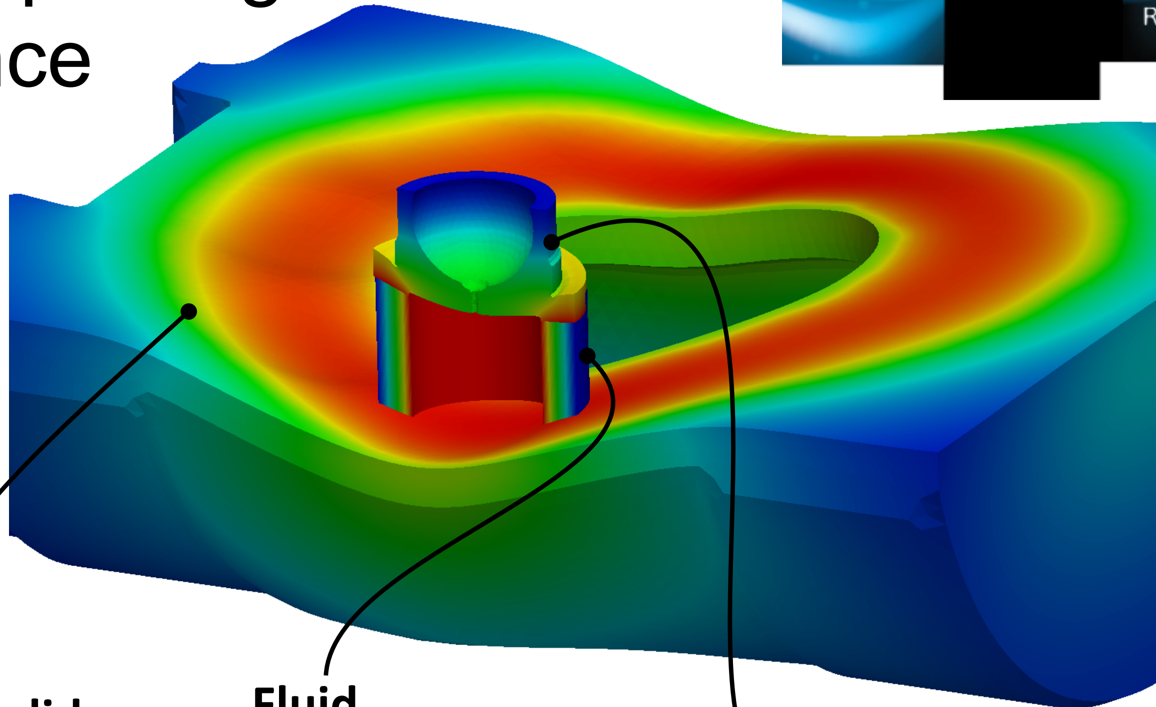
Micro motion of parts influences pressure field



Reynolds equation

$$\frac{1}{r}\frac{\partial p}{\partial r}h^3+\frac{\partial}{\partial r}\left(\frac{\partial p}{\partial r}h^3\right)+\frac{1}{r^2}\frac{\partial}{\partial \varphi}\left(\frac{\partial p}{\partial \varphi}h^3\right)=6(\mu\ \ \omega\frac{\partial h}{\partial \varphi}+2\frac{\partial h}{\partial t})$$

Physics Impacting Lubrication Performance



Swashplate Solid Body

- Pressure Deformation
- Heat Conduction

Fluid

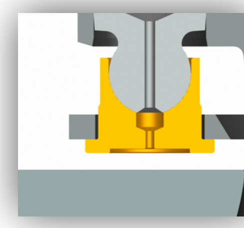
- Thin Lubricating Film Pressure
- Thin Lubricating Film Temperature
- Pocket Pressure

Slipper Solid Body

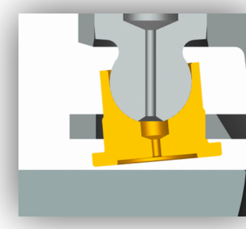
- Load Adaptive Micro-Motion

Pressure Deformation

- Heat Conduction
- Thermal Deformation

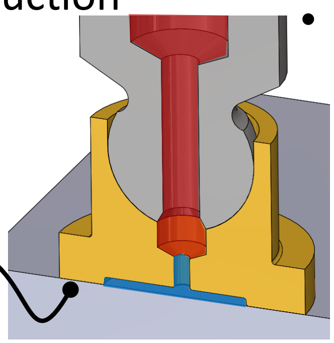


z-translation



x&y-rotation

Sealing land

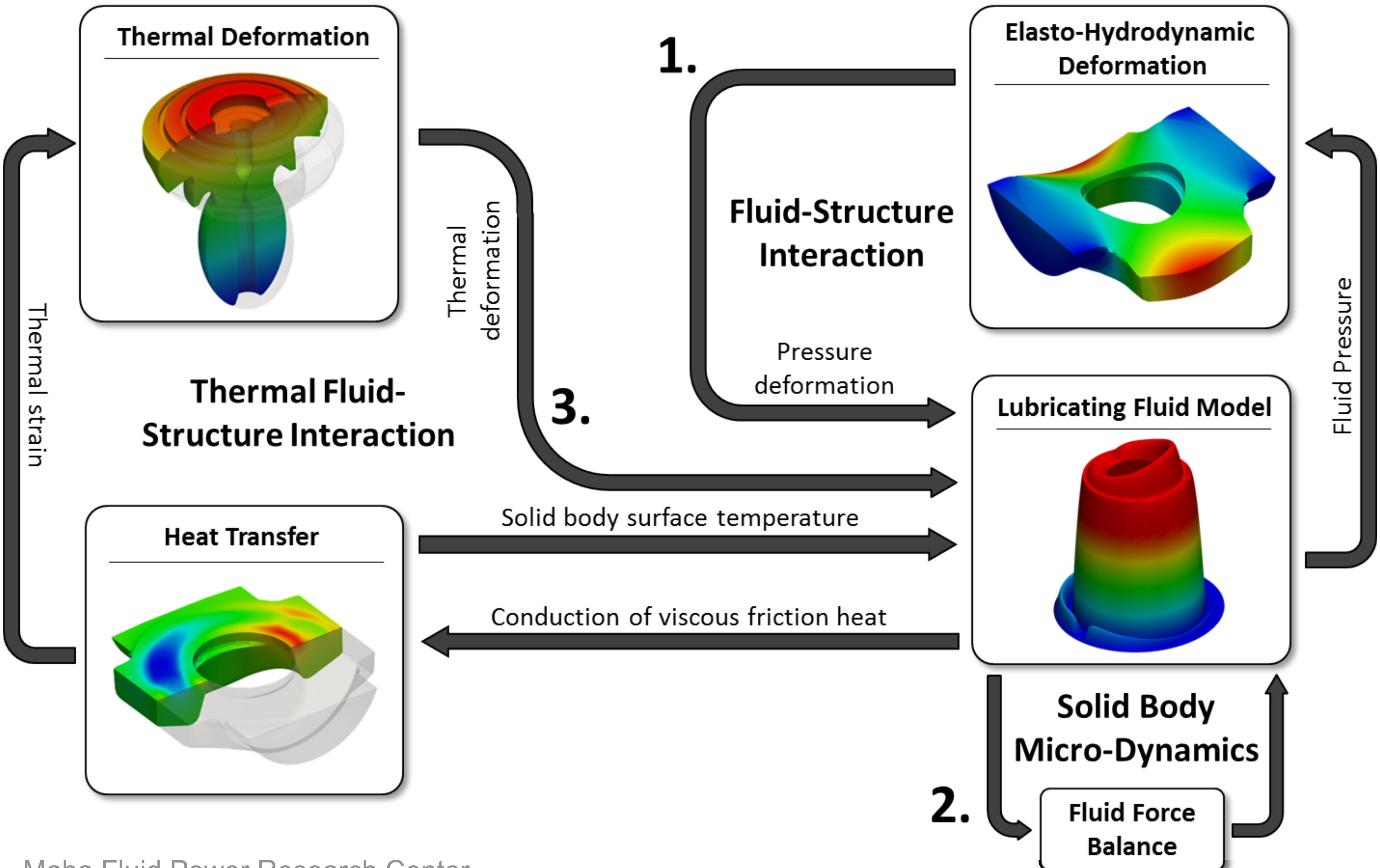


Fluid Film Modeling

requires a fully coupled multi-domain model

to describe complex thermo-elastic fluid structure interaction phenomena

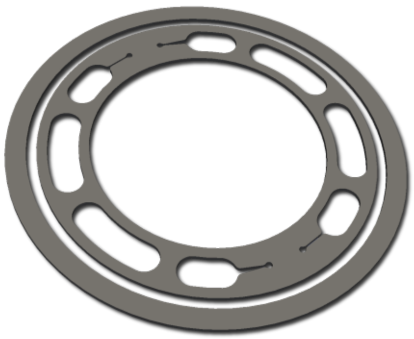
Example Slipper

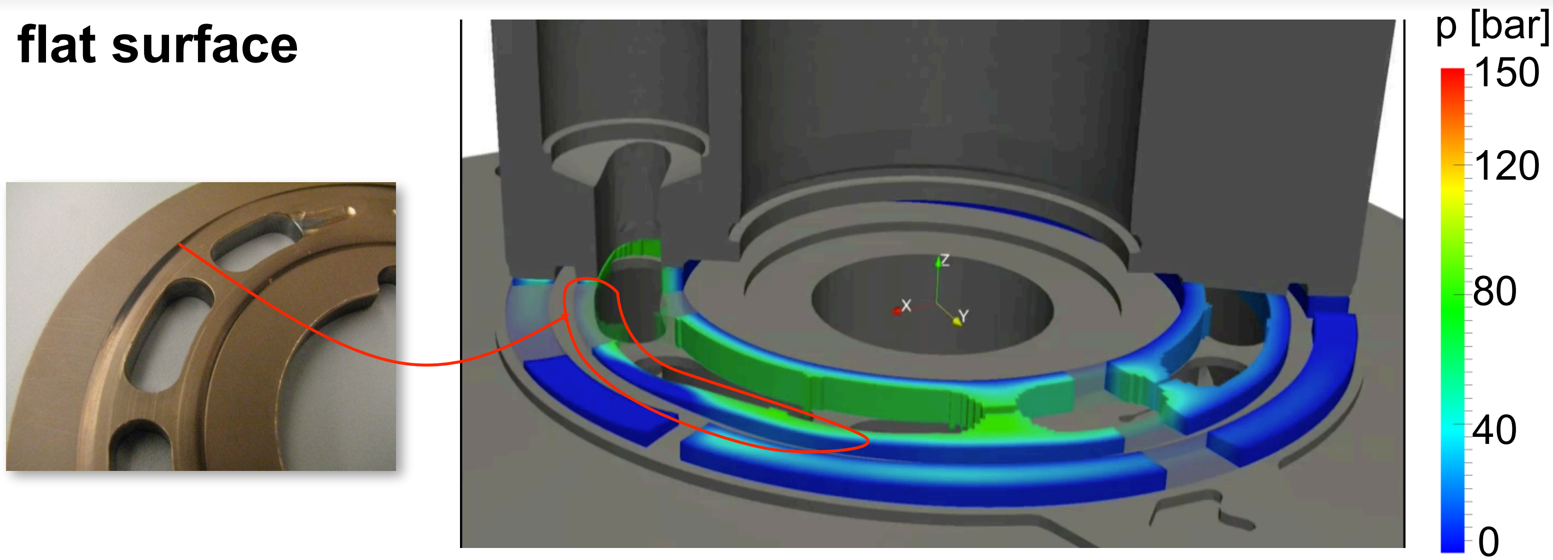


Opportunities for new directions in pump design

Micro-Shaped Surface Design

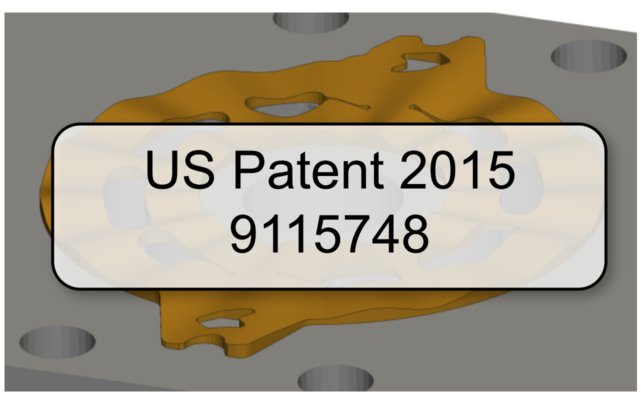
Standard design, flat surface

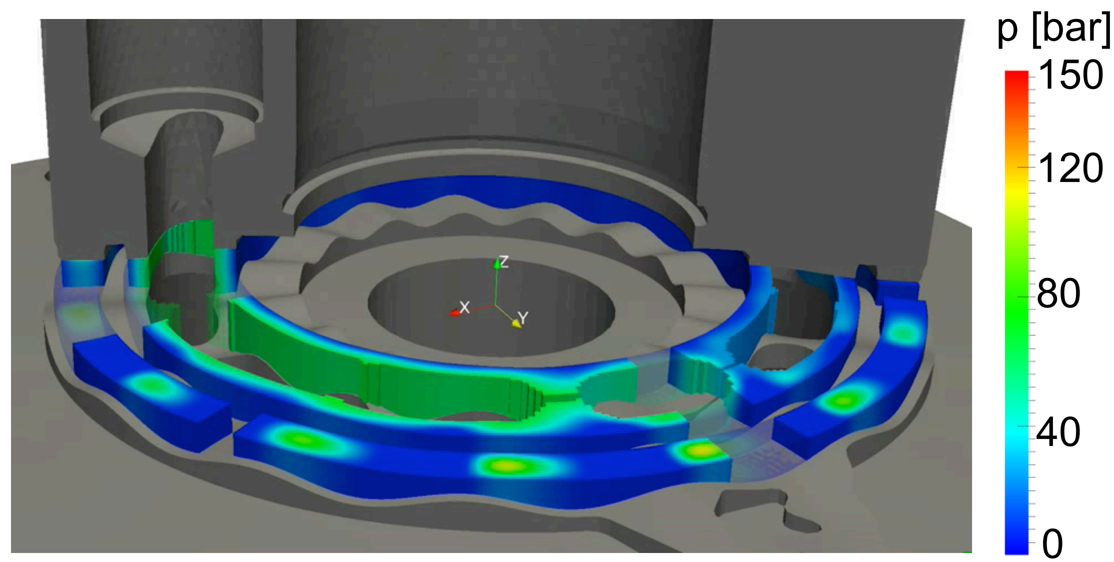




Circumferential wave pattern

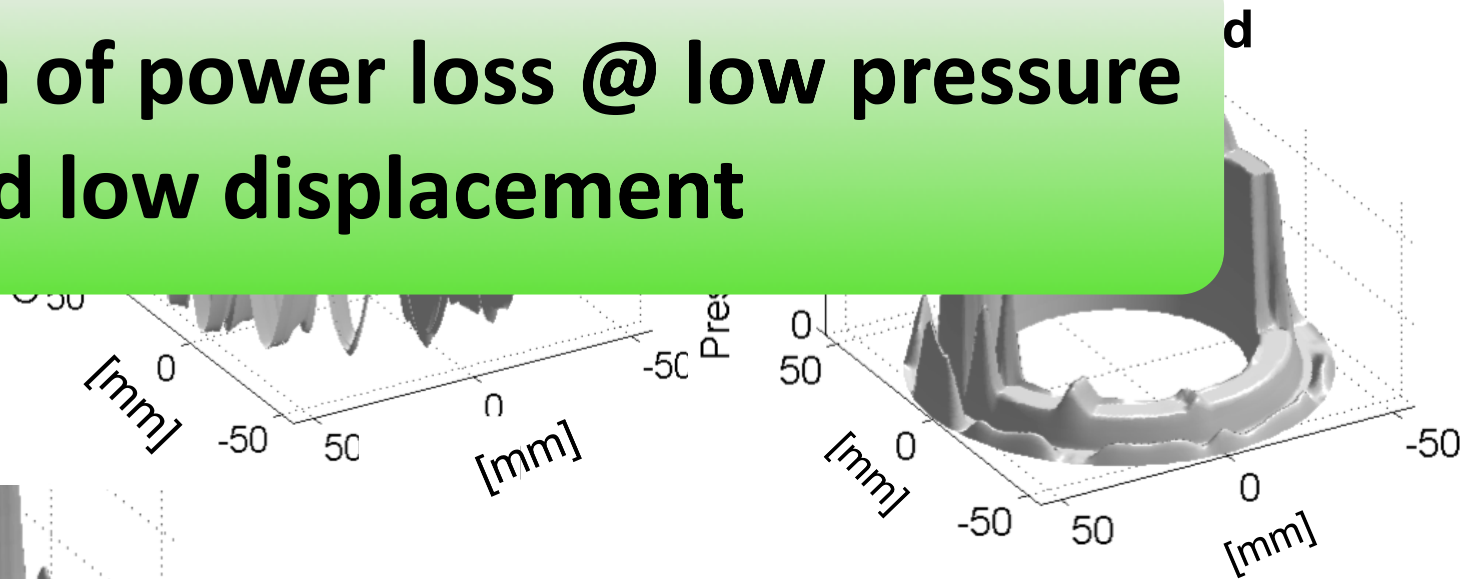
A few µm amplitude, 15 peaks

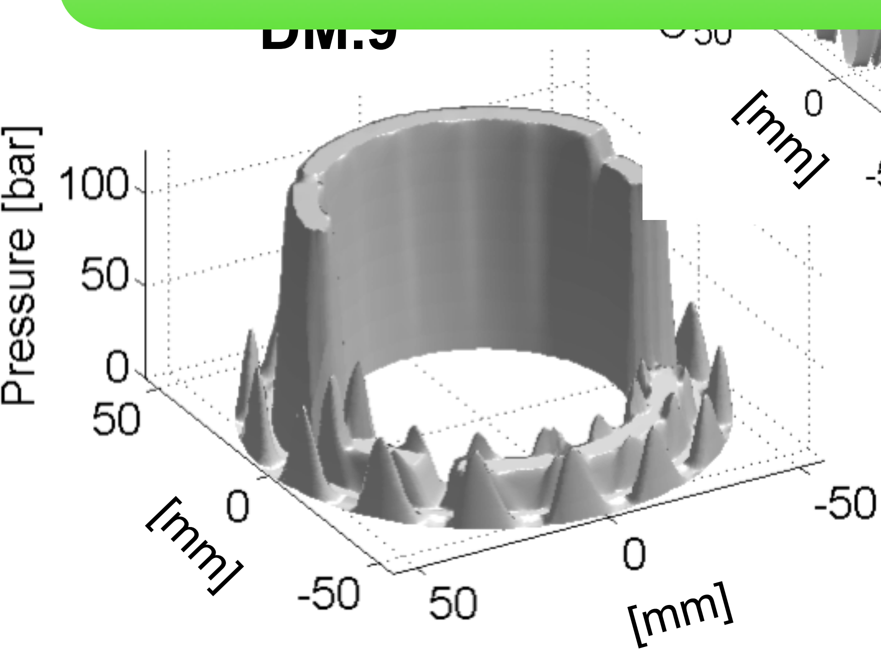




Simulation Results

60% reduction of power loss @ low pressure and low displacement



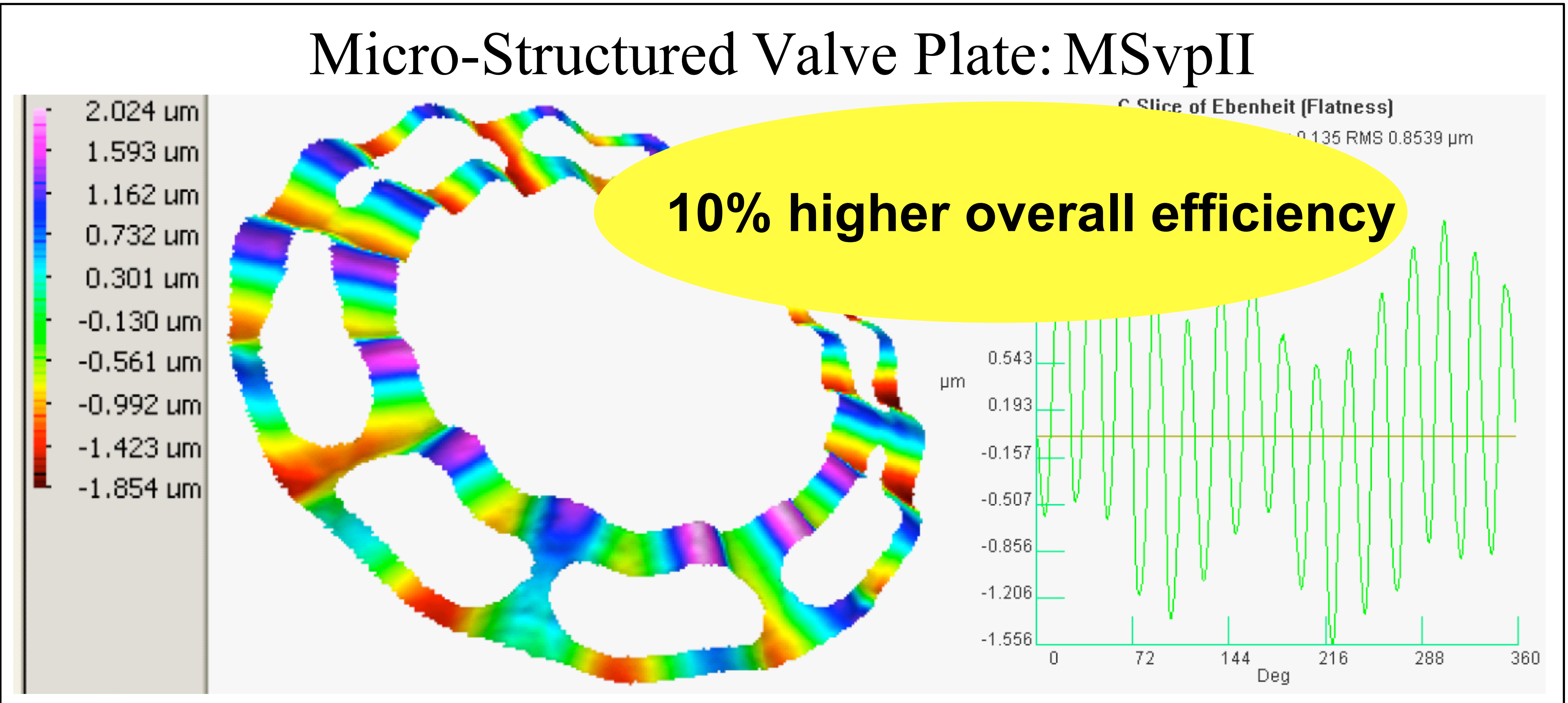


Increases gap height

Decreases viscous friction

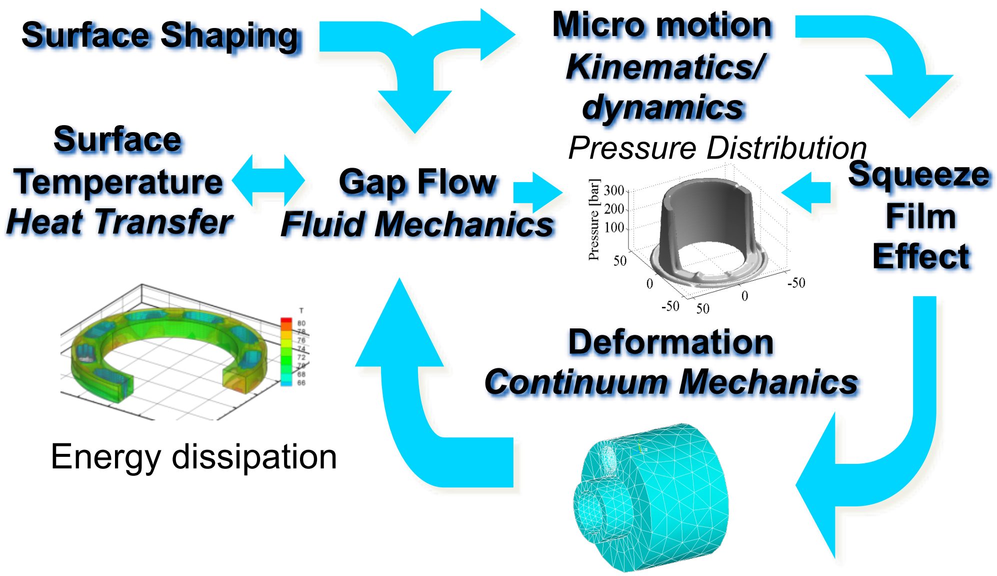
Increases Load Capacity

Prototype valve plate



Digital prototyping

Physical based Model



Computationally Expensive

\+ Design creativity

Surface shaping

New material combinations

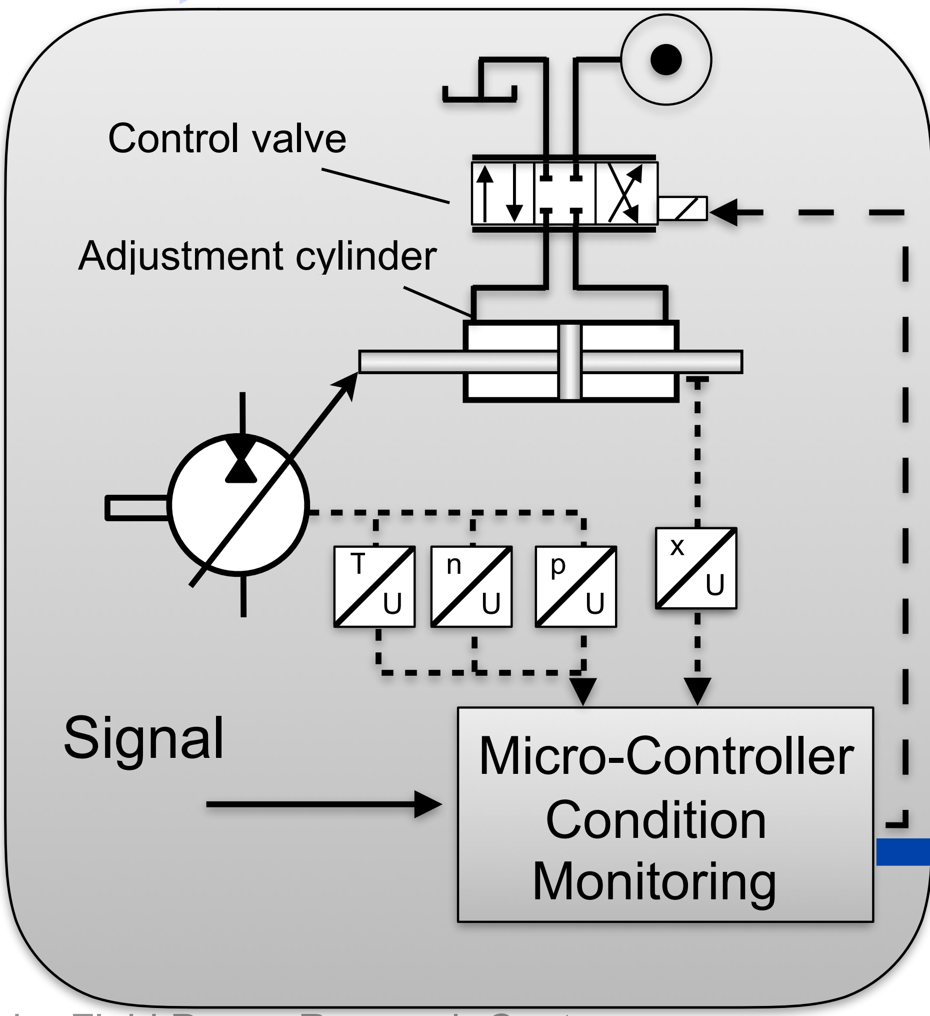
New manufacturing technologies

a new area of pump design

Innovations in design of smart pumps

Smart Pump Design

- Optimize valve plate design to reduce control power
- Control valve determines pump dynamics



- integrated swash plate sensor
- integrated microcontroller
- integrated control SW
- integrated pressure, speed & temperature sensors
- on demand prognostics

cloud communication

Thank You!