Energy savings through displacement control - an opportunity and challenge for Fluid Power

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Content

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1. Introduction & state of the art
2. Displacement controlled actuation
3. Prototype machines
4. Energy & fuel savings demonstrated
5. Hybrid DC systems

State of the Art in Fluid Power

Hydraulic resistances used for motion control

33% energy wasted

15% energy wasted

Low effici... motors

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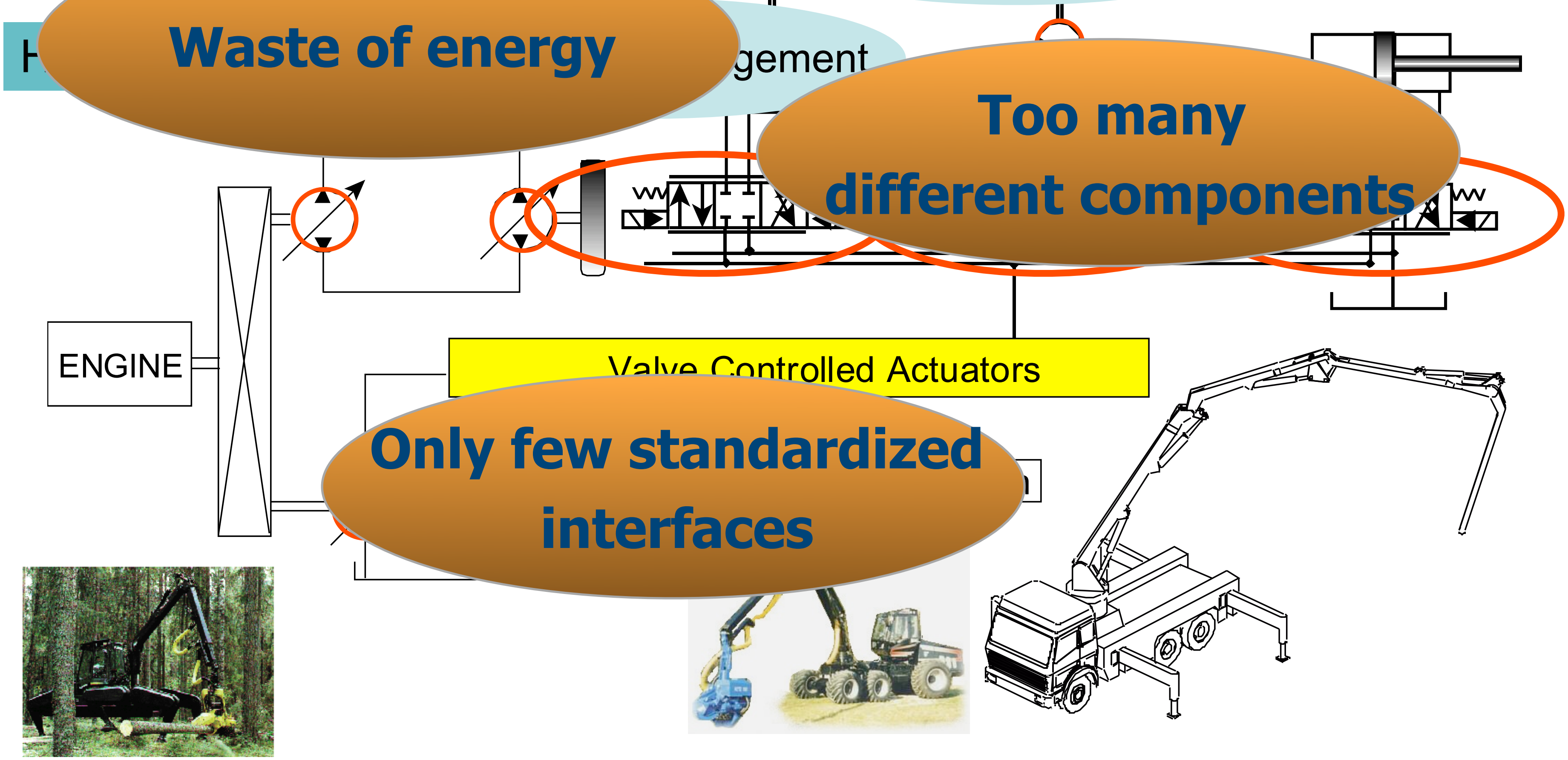
Waste of energy

Too many different components

Only few standardized interfaces



Major question being answered

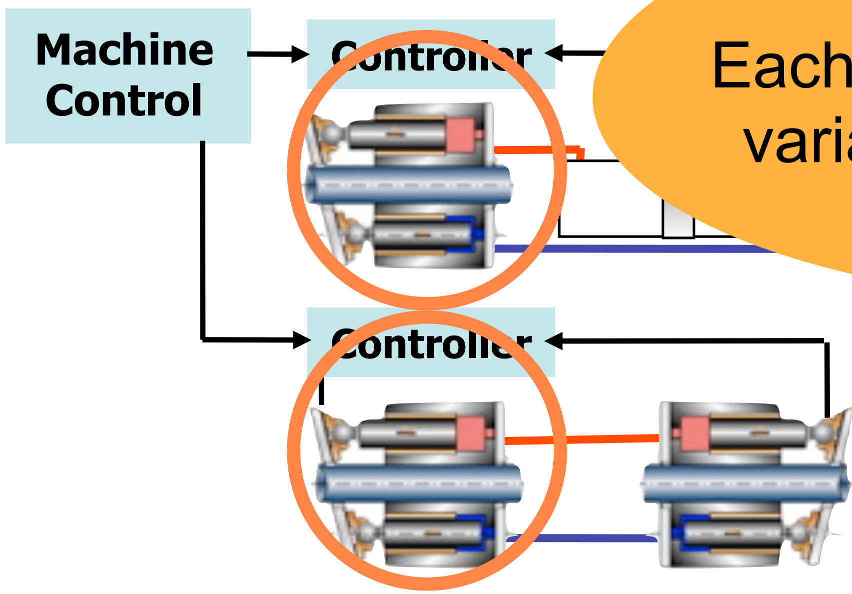
How much can efficiency of these multi actuator machines be improved with ***new system architectures, more advanced or new components,*** *and* ***new control algorithms?***

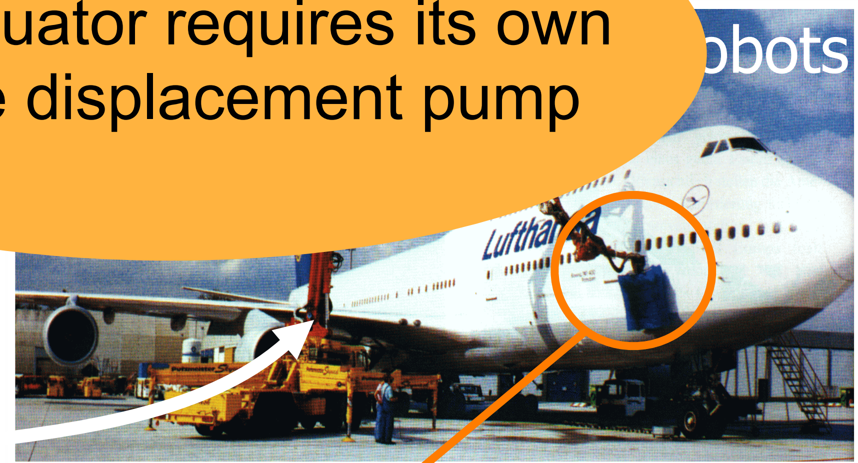
How are these concepts ***transformational?***

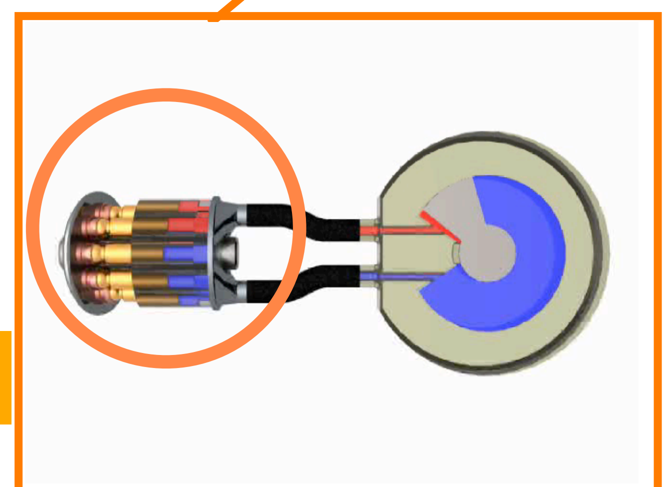
Our System Approach

- **Energy Savings by Th** **Technology**

Each actuator requires its own variable displacement pump





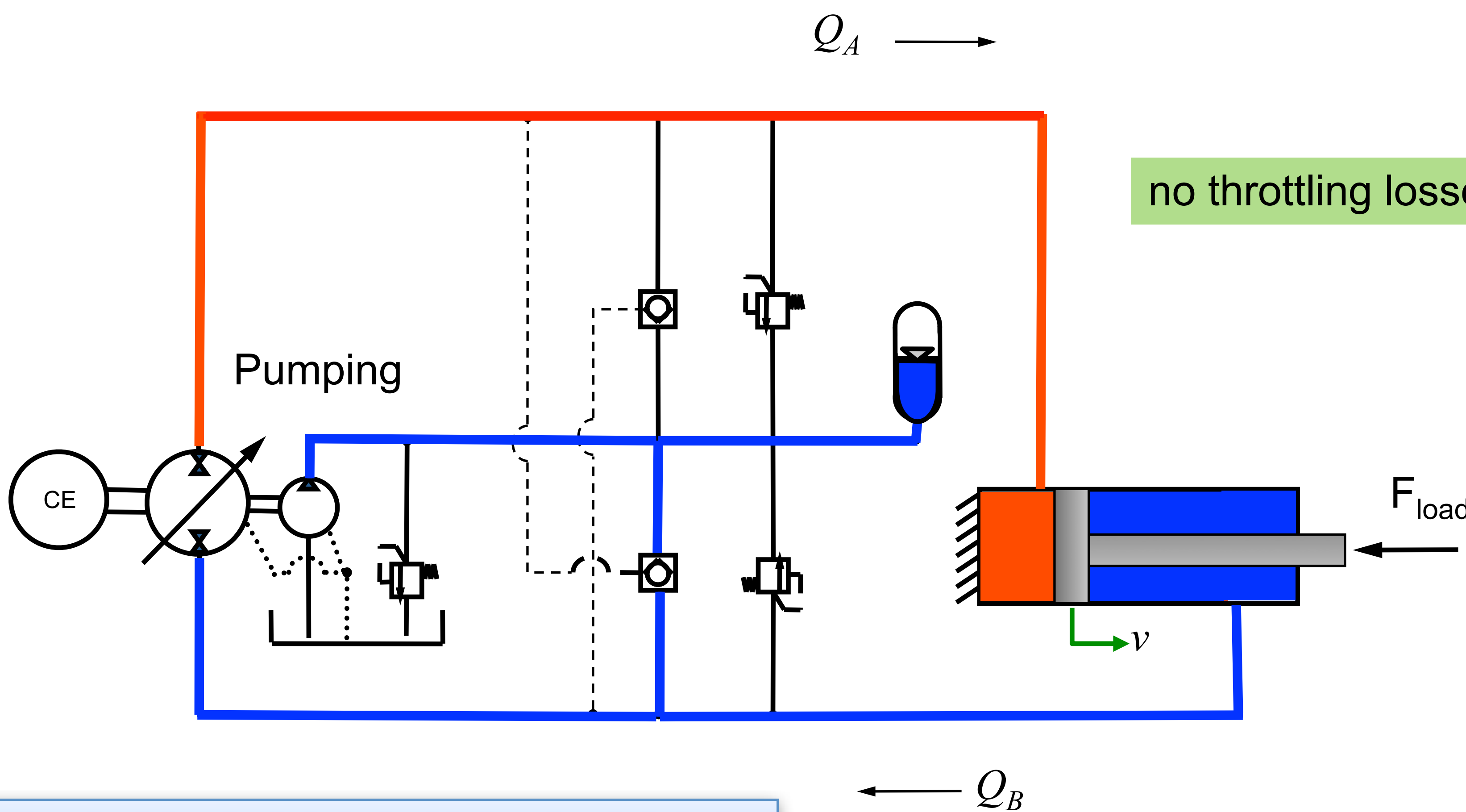


- **energy recovery**
- **no throttling losses**

Pump controlled actuator

Displacement Control
- new circuit for linear actuators

Circuit 1st published @ 1st Bratislavian Fluid Power Symposium in 1998 in Casta Pila

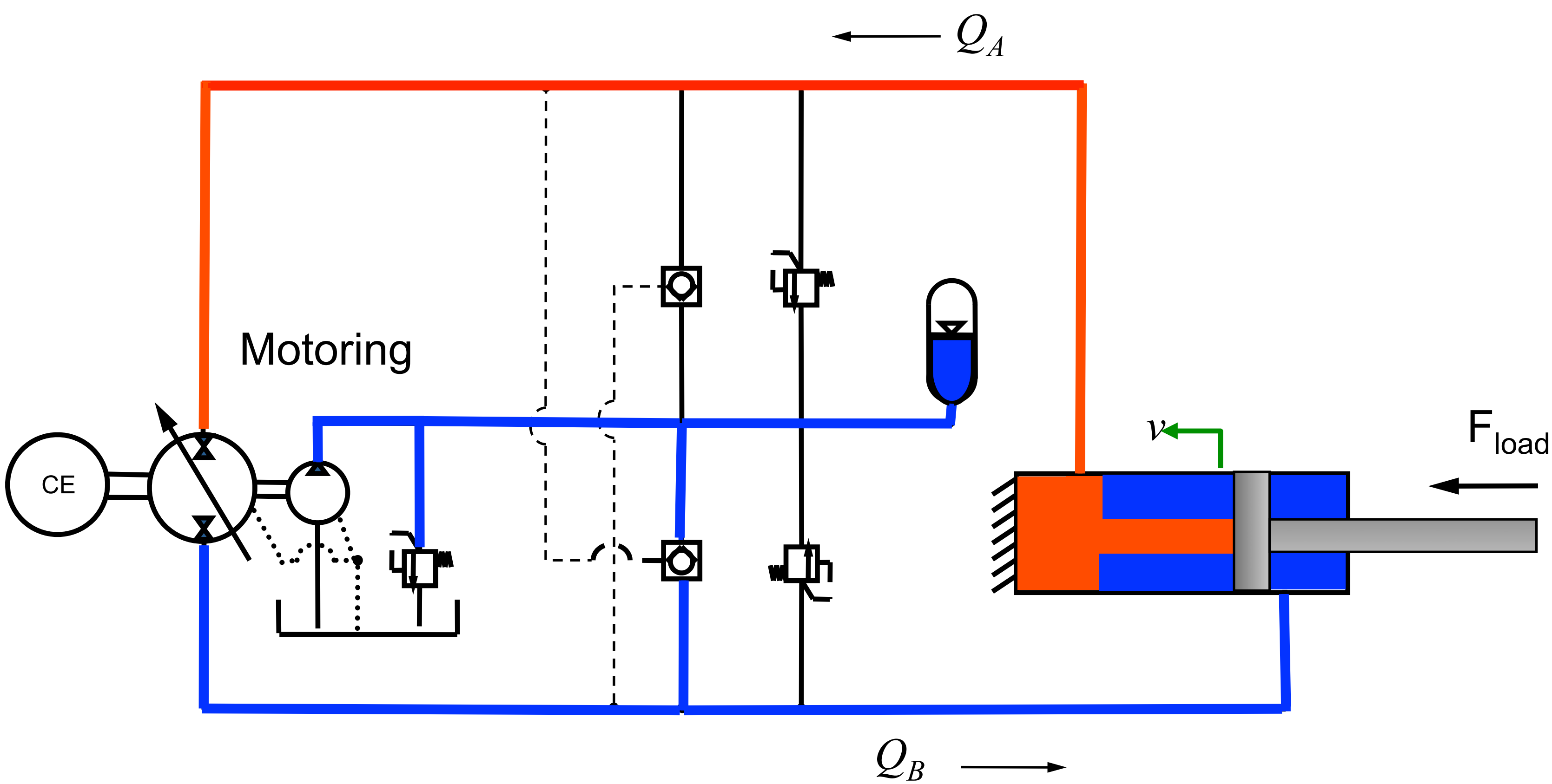


no throttling losses!

Operation in Pumping Mode

Displacement Control

Operation in Motoring Mode



energy recovery!

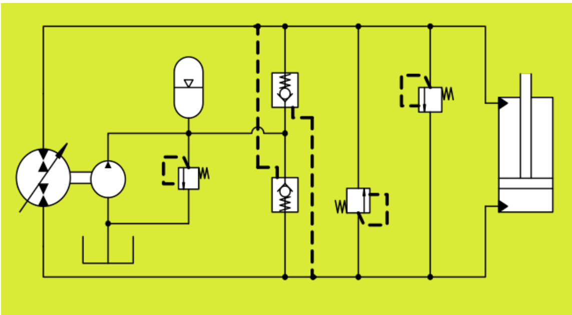
Advantages of DC circuits

No Resistance control

Better use of primary energy & energy recovery

- Less components, easy interface → System simplification
- Less fuel consumption → Lower operating costs
- Less heat generation → Reduction of cooler
- Machine function via SW → Easy to control
- Improved operator feeling → Higher productivity

History of Displacement Control



Rahmfeld, R. and Ivantysynova, M. 1998. Energy Saving Hydraulic Actuators for Mobile Machines. Proceedings of 1st Bratislavian Fluid Power Symposium, pp. 47-57. Častá-Píla, Slovakia.

2001 DC wheel loader prototype @ TUHH with O&K
15% less fuel measured in comparison test

2003 2nd wheel loader prototype @ TUHH with CNH
DC + New transmission+Active damping

2010 Mini excavator @ Purdue
40% less fuel measured by CAT

2007
Skid steer loader @ Purdue
15-20% less fuel and active damping

DC Controlled Excavator

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435H Bobcat Mini Excavator

Engine: Kubota 2.0 liter diesel, 37 kW

Machine weight: 5 000 kg

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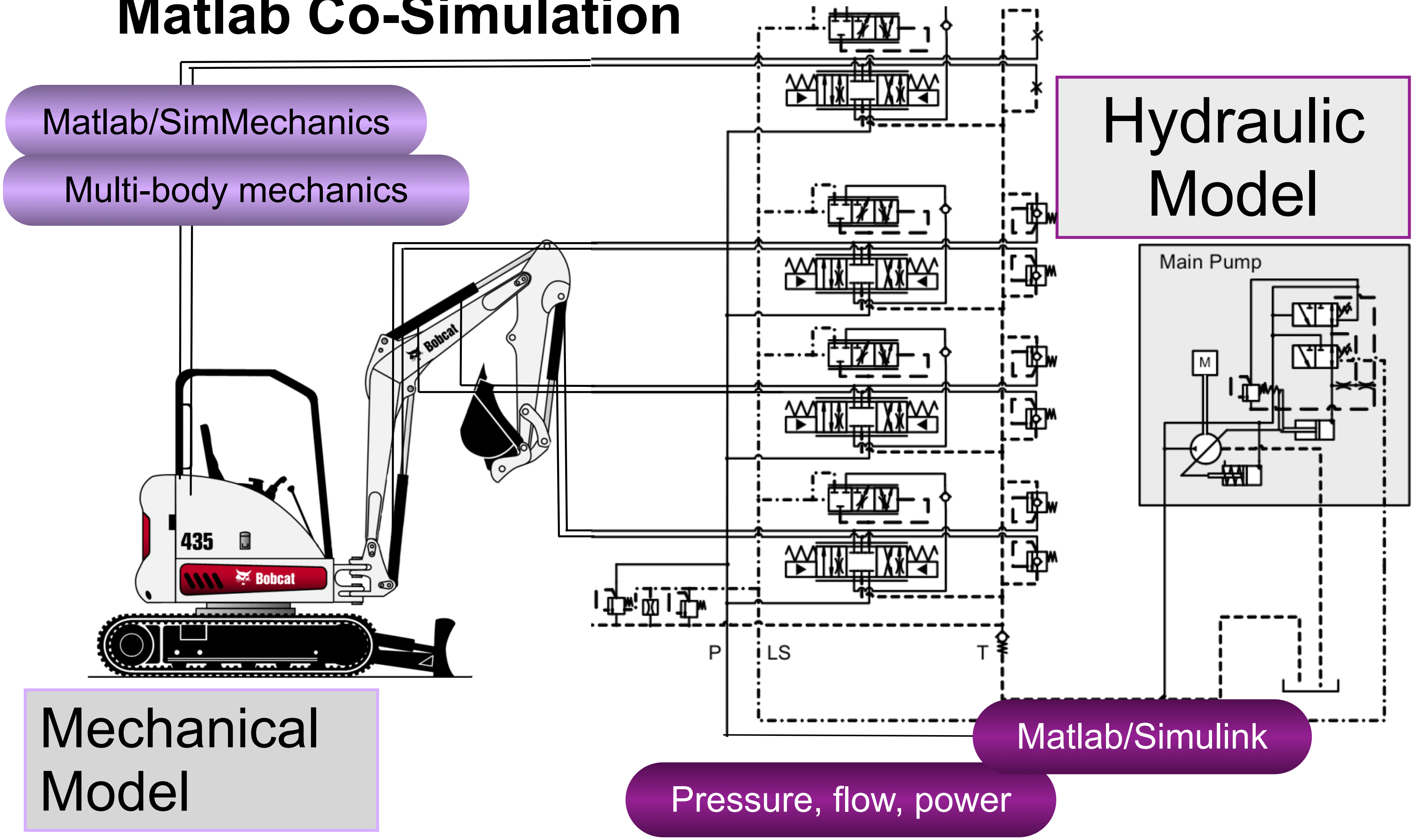
Analyze LS - System

Matlab Co-Simulation



Simulation Results

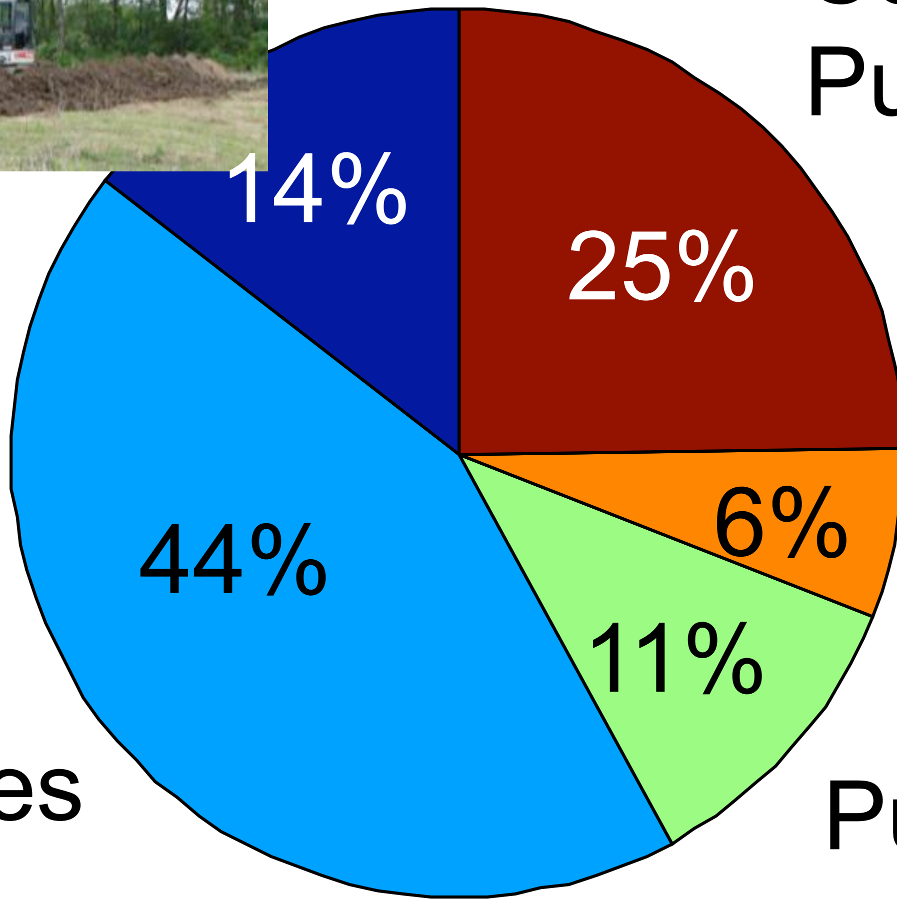
Define typical machine operations

Trench Digging cycle

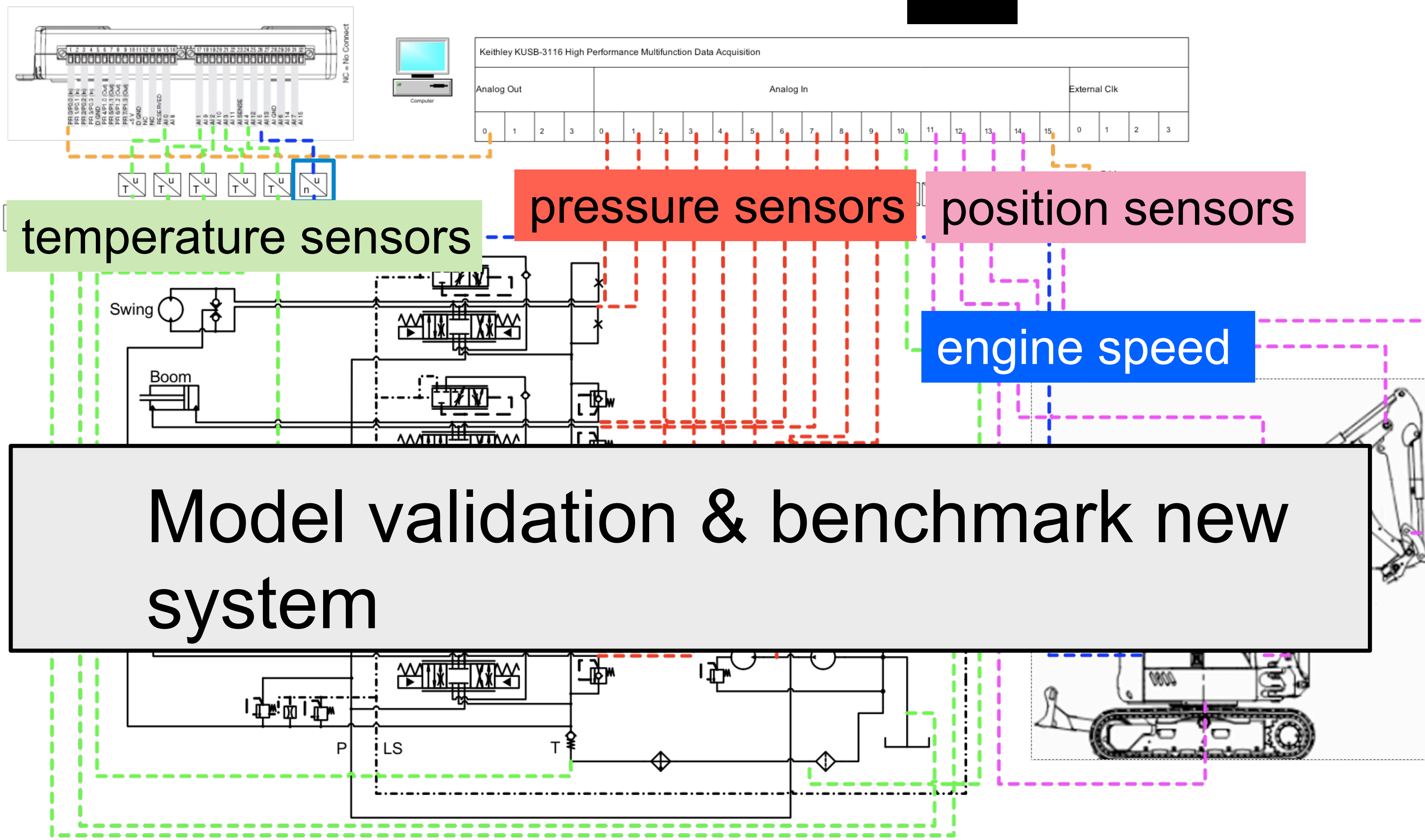
Simulation Results

LS Excavator System

Trench digging cycle



Baseline Instrumentation



Model validation & benchmark new system

DC Controlled Excavator

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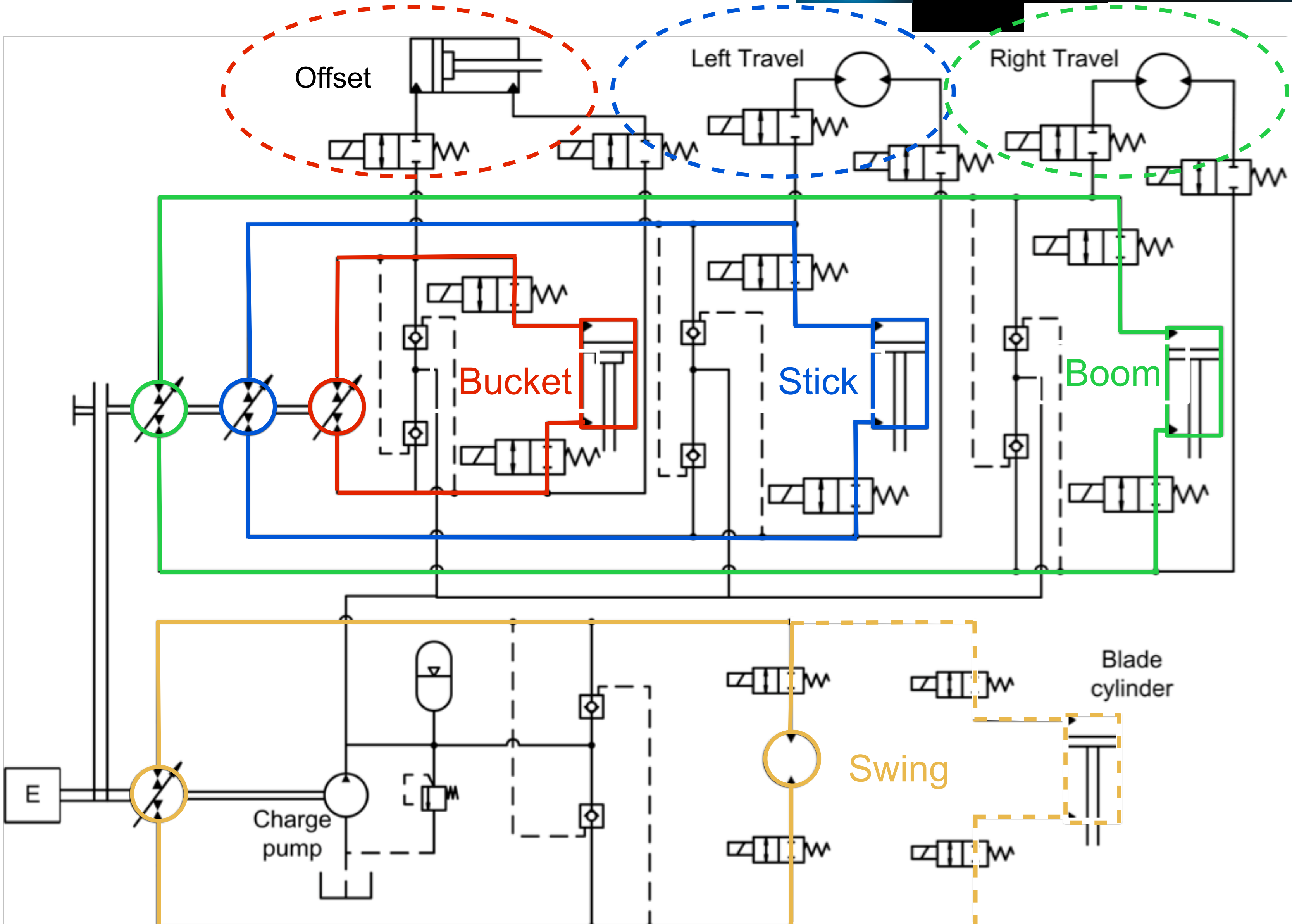

Simulation Results

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Displacement Controlled Excavator System

Trench digging cycle

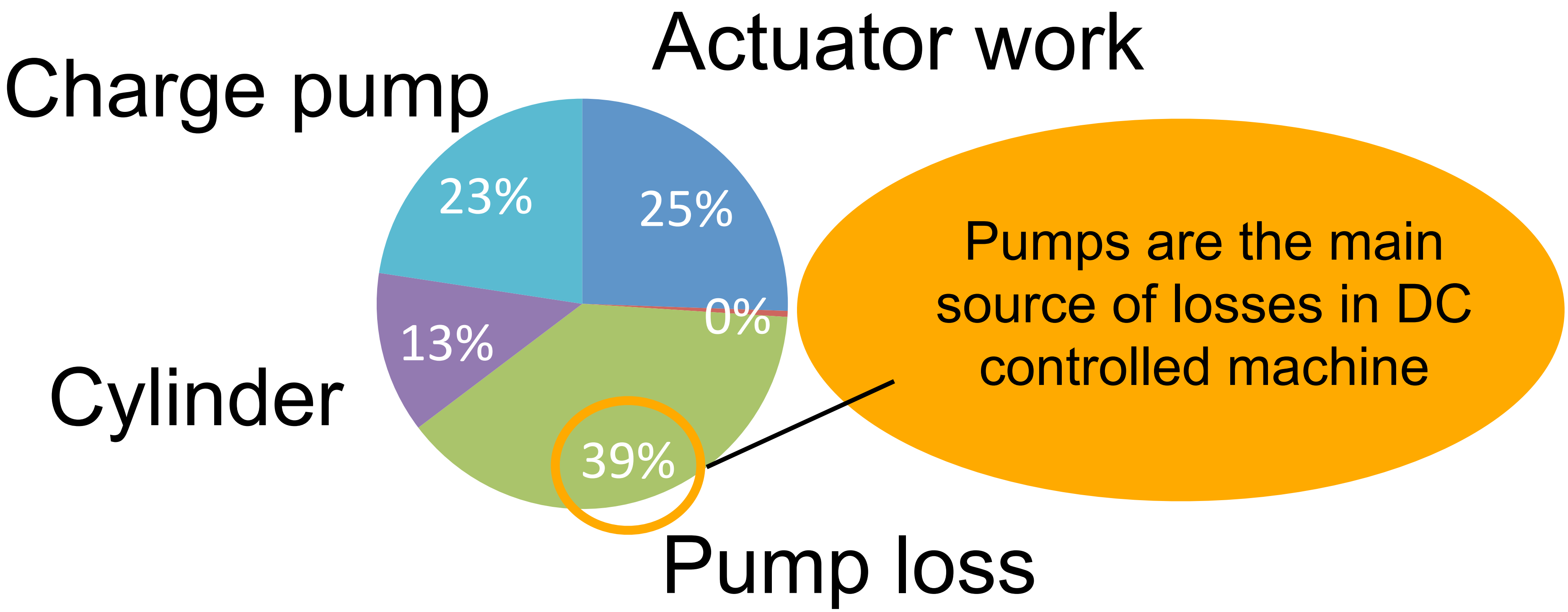
39% less energy consumed for same cycle

by eliminating throttling losses and energy recovery

Simulation Results

Displacement Controlled Excavator System

Trench digging cycle



Side by side machine test

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90° truck loading cycle @ CAT test facility

Side by side machine test

Results

Raw data, average of selected cycles

Machine	Soil loaded (ton)	Fuel consumed (kg)	Cycle time (s)
Standard	7.55	0.533	12.1
Prototype	7.66	0.321	10.4
Difference	**+1.5%**	**-39.7%**	**-14.1%**

40% less fuel

Side by side machine test

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Results

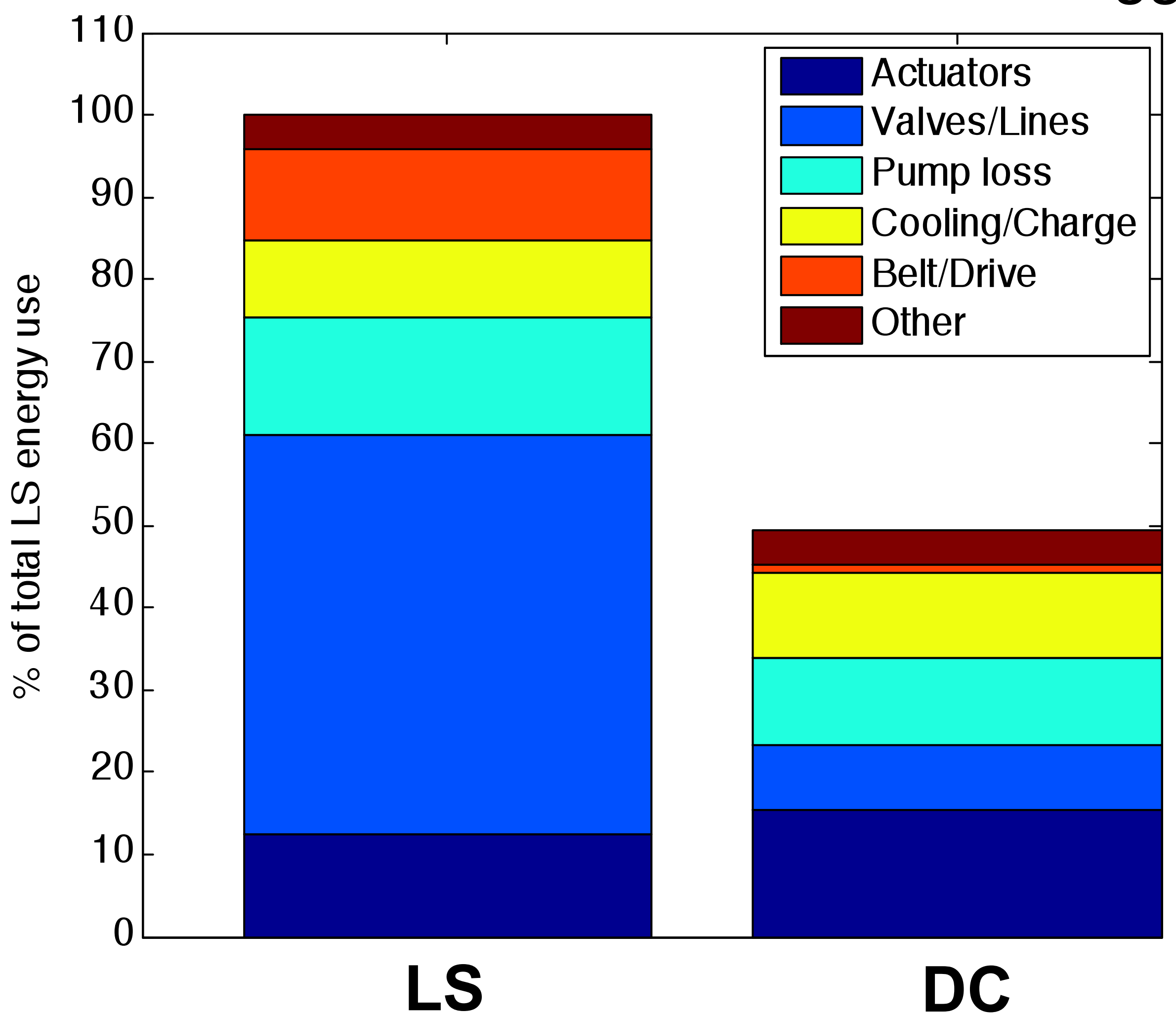
Calculated results for selected cycles

Machine	Fuel Consumption (l/h)	Productivity (t/h)	Efficiency (t/l)
Standard LS	9.36	101.7	10.9
Prototype DC	6.57	120.9	18.4
Difference	**-29.8%**	**+18.9%**	**+69.4%**

70% productivity increases

Energy use comparison

based on simulation models for same digging cycle



50 % energy savings

Reduced hydraulic losses
Reduced engine loads

Reduced cooling demands

Multi-actuator machines

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Pump Sharing

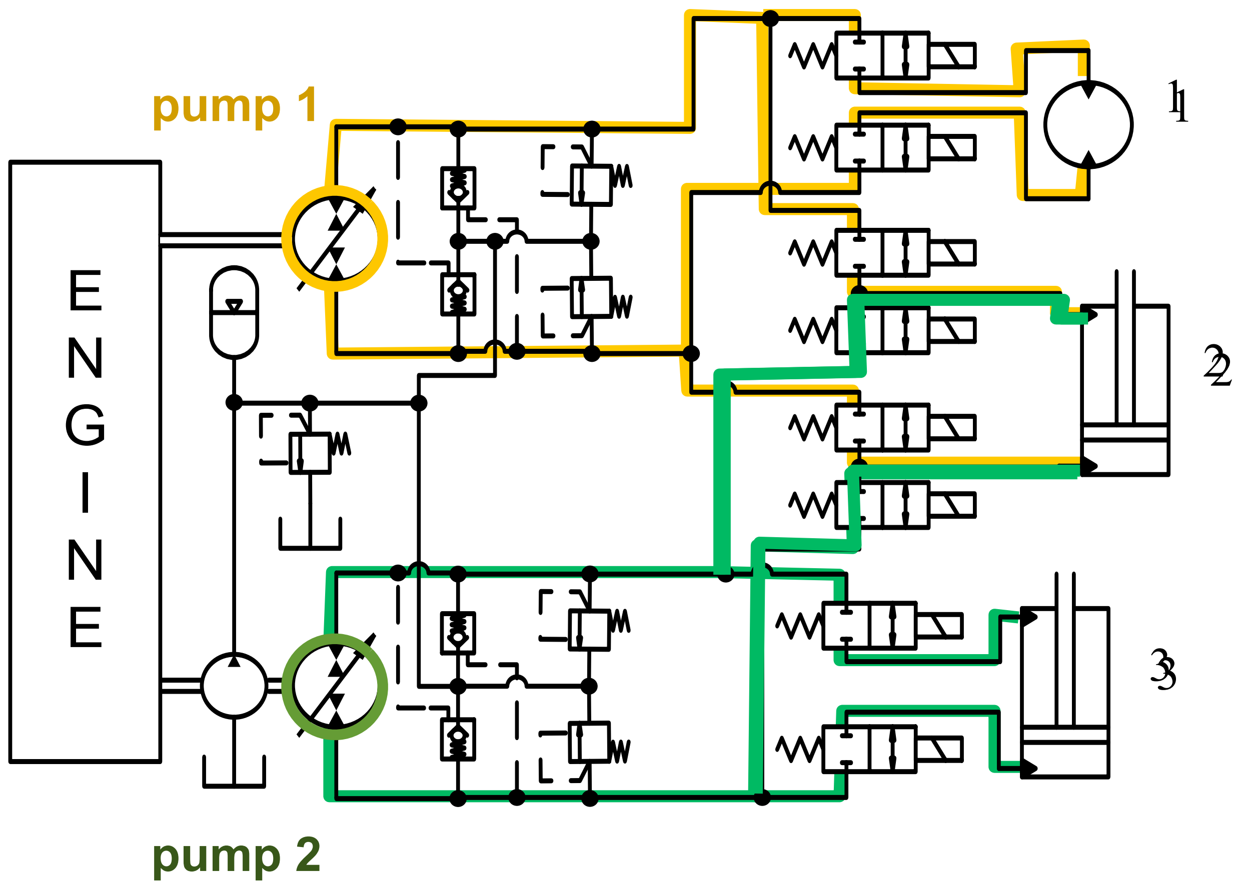
US Patent 8,191,290 B2 issued June 5, 2012

Advantages

- Fewer pumps than actuators
- Lower parasitic losses
- Combined pumps flows

Limitation

- Simultaneous operations limited to # pumps



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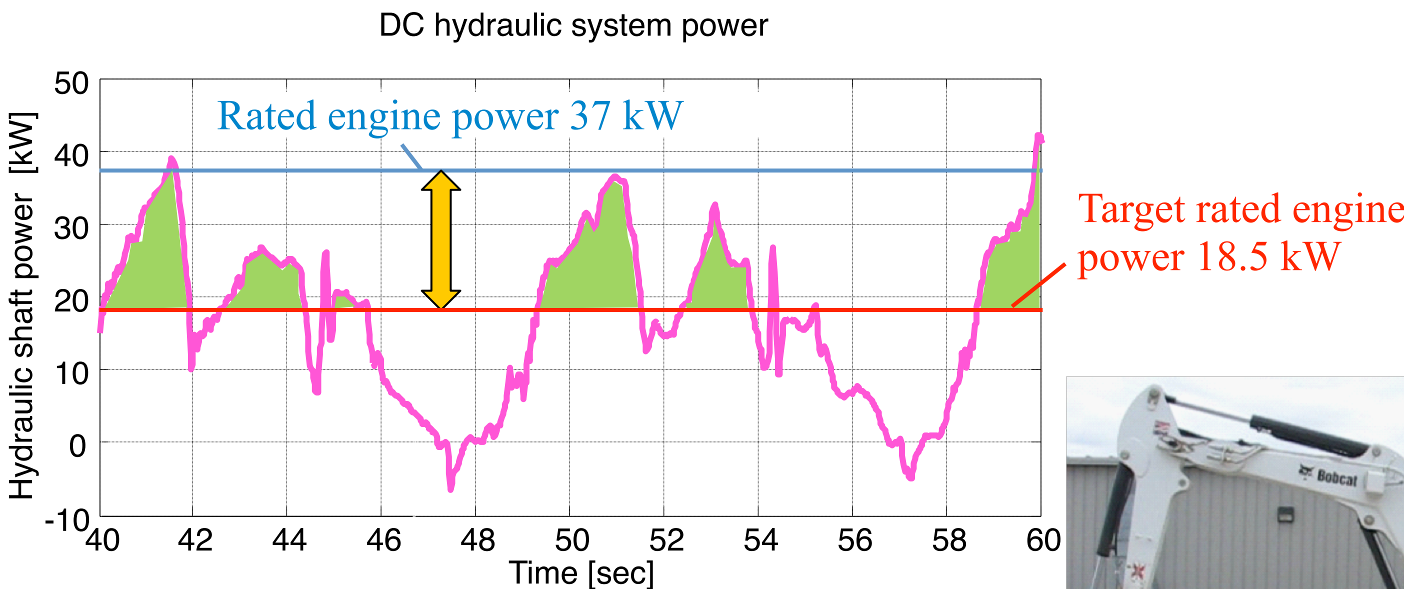
Hybrid DC Systems

allow engine downsizing and further fuel savings



Hybrid DC Systems

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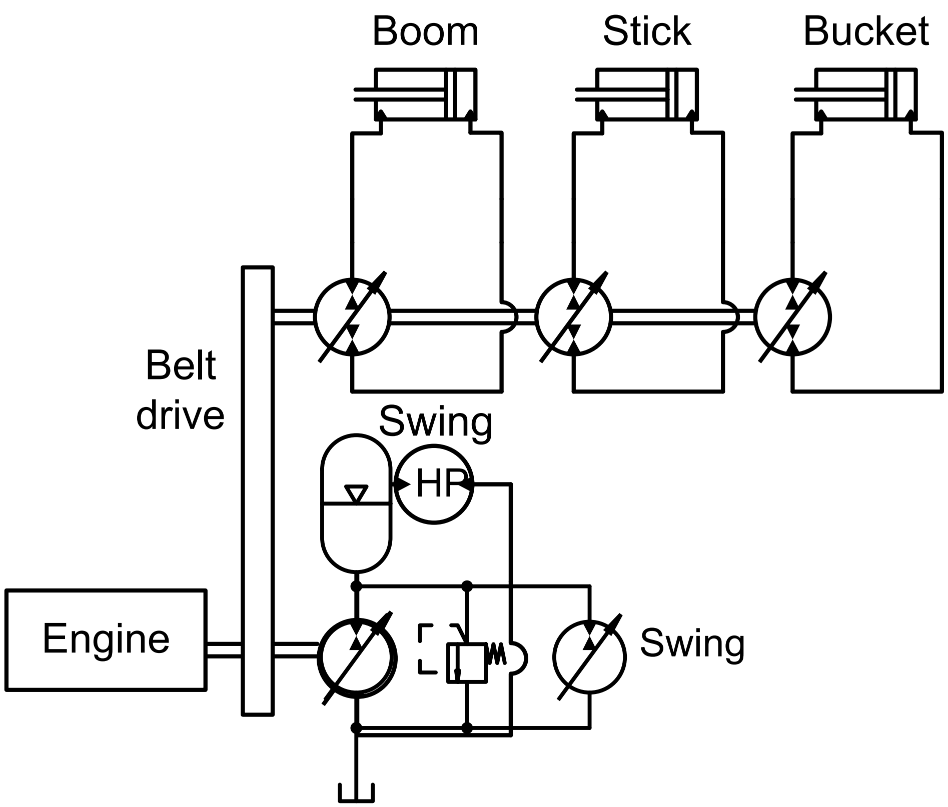
series- parallel arrangement



US Provisional Patent Application
Serial No. 61/453.368

Benefits

- energy storage without adding a pump
- load leveling
- all rotary actuator can share one pump
- high pressure rail can be used for pump controls
- valves can be added for on/off functions

Pump & Motor Requirements

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highly efficient electro-hydraulically controllable variable pumps & motors

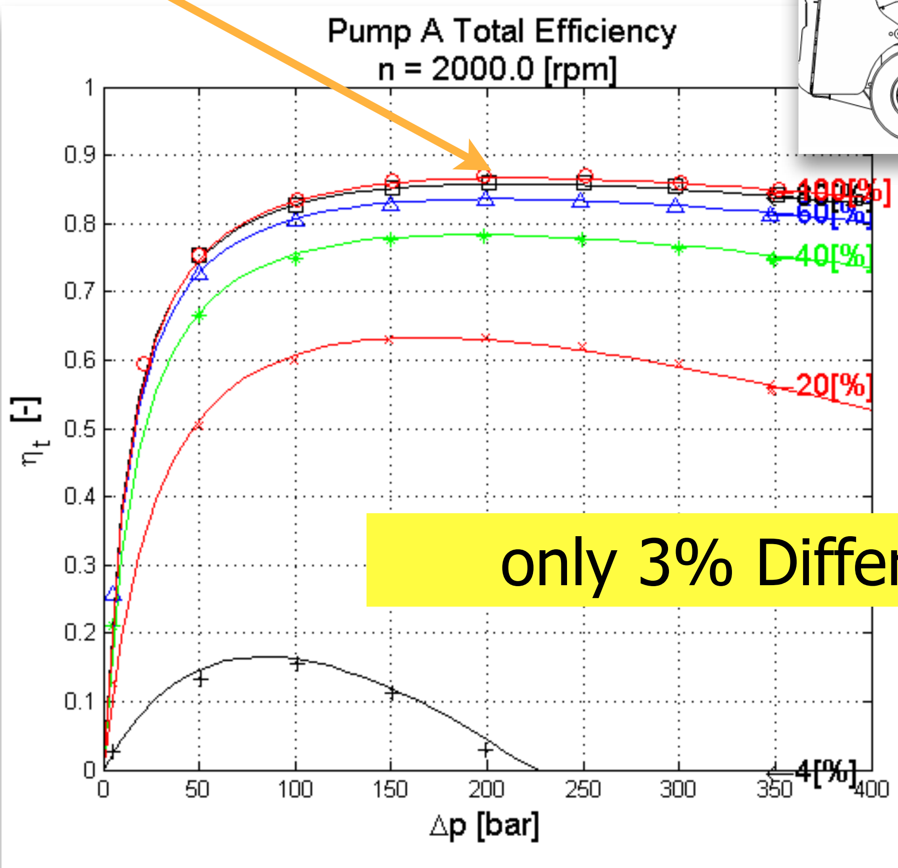
- **Increase of Efficiency**

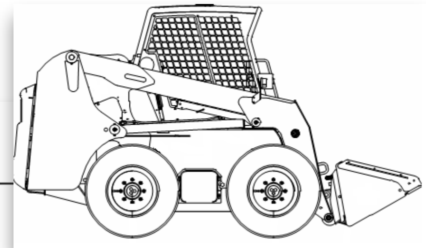
Simulation Results

why so important?

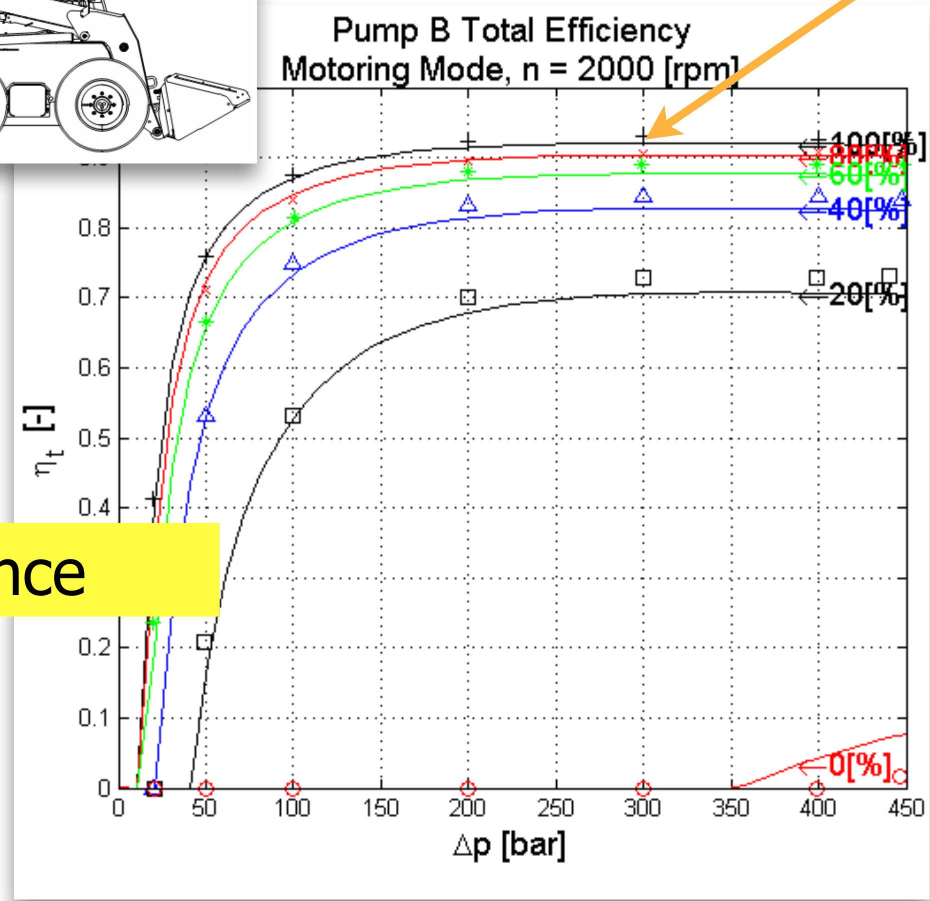
Example - efficiency

$\eta_{t\ max}=0.88$





$\eta_{tmax}=0.91$



only 3% Difference

Willimanson, C. and Ivantysysnova, M. 2007. The effect of pump efficiency on displacement controlled actuator systems. Proceedings. 10th SICFP'07, Tampere, Finland, Vol. 2, pp. 301-326.

Example - efficiency

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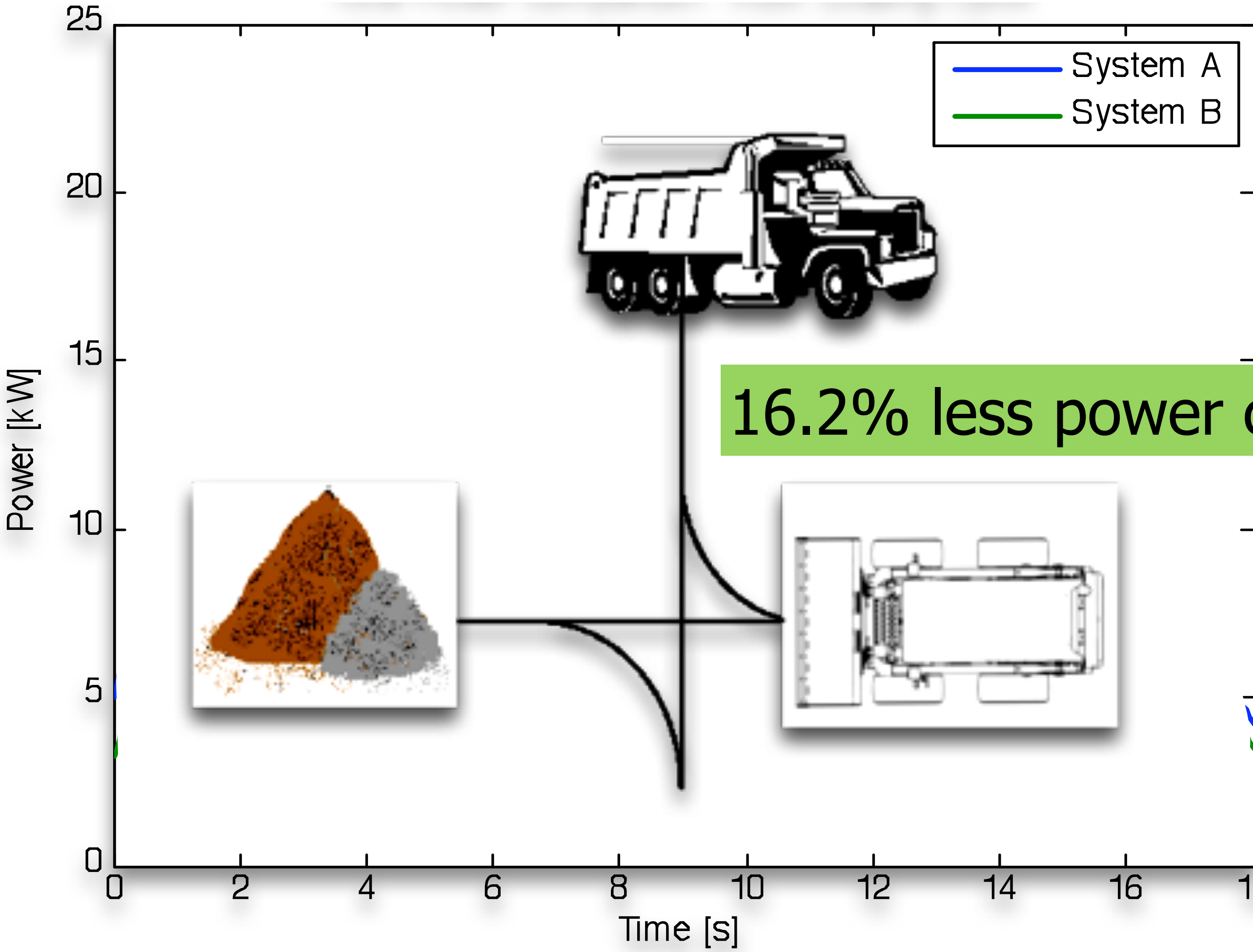
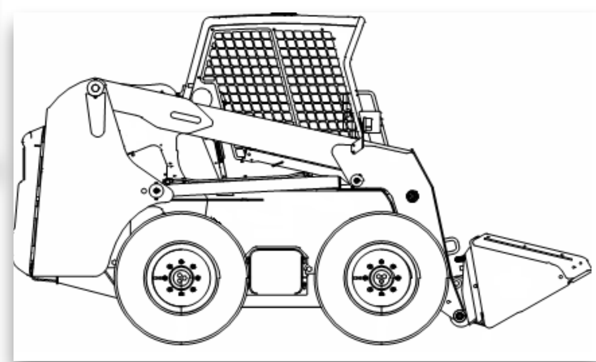
Skid steer loader - Truck loading Cycle



16.2% less power consumption



Pump & Motor Requirements

highly efficient electro-hydraulically controllable variable pumps & motors

- **Increase of Efficiency**
- **Smart Pumps - Advanced Pump Control**
- **Increase of Power Density**
- **Low Noise Emission**

Thank You!