



A Novel Multi-pump System for Hydraulic Actuation in Electric Mobile Machinery

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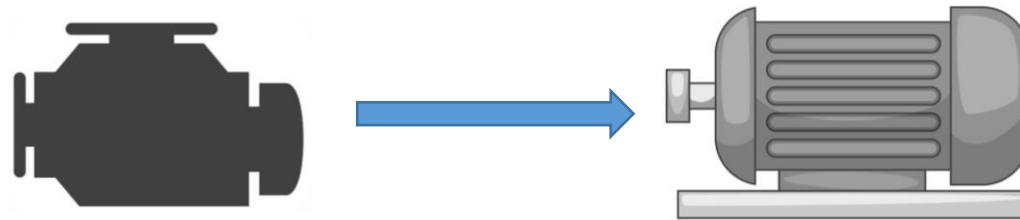
Kim Heybroek, Volvo CE

Liselott Ericson, Linköping University

- Research background and motivation
- Pump-controlled systems
- Multi-pump system proposal
- Goals and next steps



- Global emission reduction goals to be reached until 2050¹
- Industry emissions:
 - Construction industry: 20% of global emissions² (6% of the 20%, 315 million tons of CO₂, is from fossil fuels consumption³)
 - Mining industry: 4-7% of global emissions⁴
- Development of hybrid and fully electric machines is one option to reduce the direct emissions



- New opportunities and challenges for the actuation systems
- Improving systems efficiency is desirable because of the limited battery capacity

¹ <https://www.un.org/en/climatechange/net-zero-coalition>

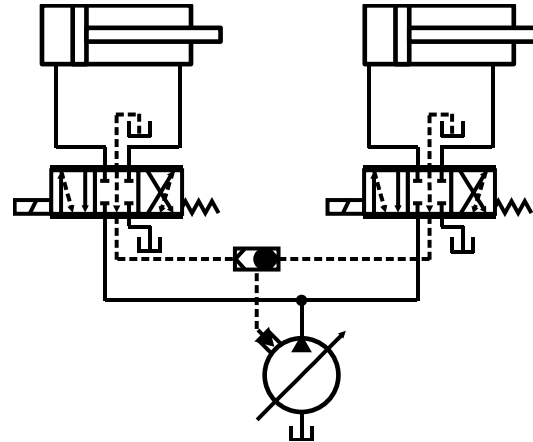
² Research Report: Carbon Footprint of Construction Equipment. European Rental Association, Climate Neutral Group, 2019

³ Huang, L., Renewable and Sustainable Energy Reviews (2017), <http://dx.doi.org/10.1016/j.rser.2017.06.001>

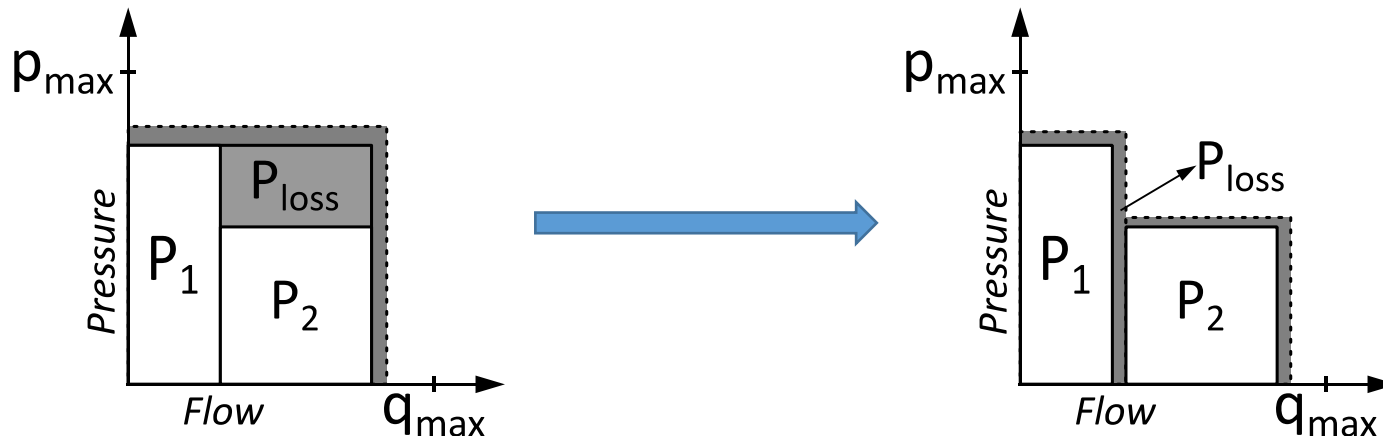
⁴ Here's how the mining industry can respond to climate change. McKinsey Sustainability, 2020. Accessed in 14/11/22:

<https://www.mckinsey.com/capabilities/sustainability/our-insights/sustainability-blog/here-is-how-the-mining-industry-can-respond-to-climate-change>

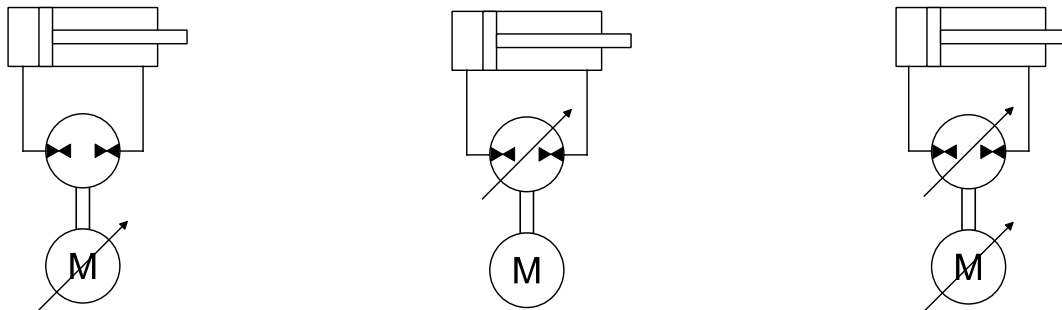
- Shared pump solutions: open-centre, load-sensing



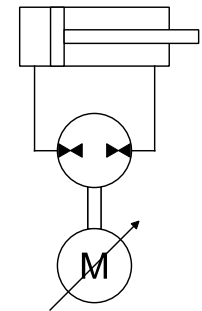
- Losses are still present when multiple loads are still used
 - For load-sensing: Separating the loads could reduce the losses



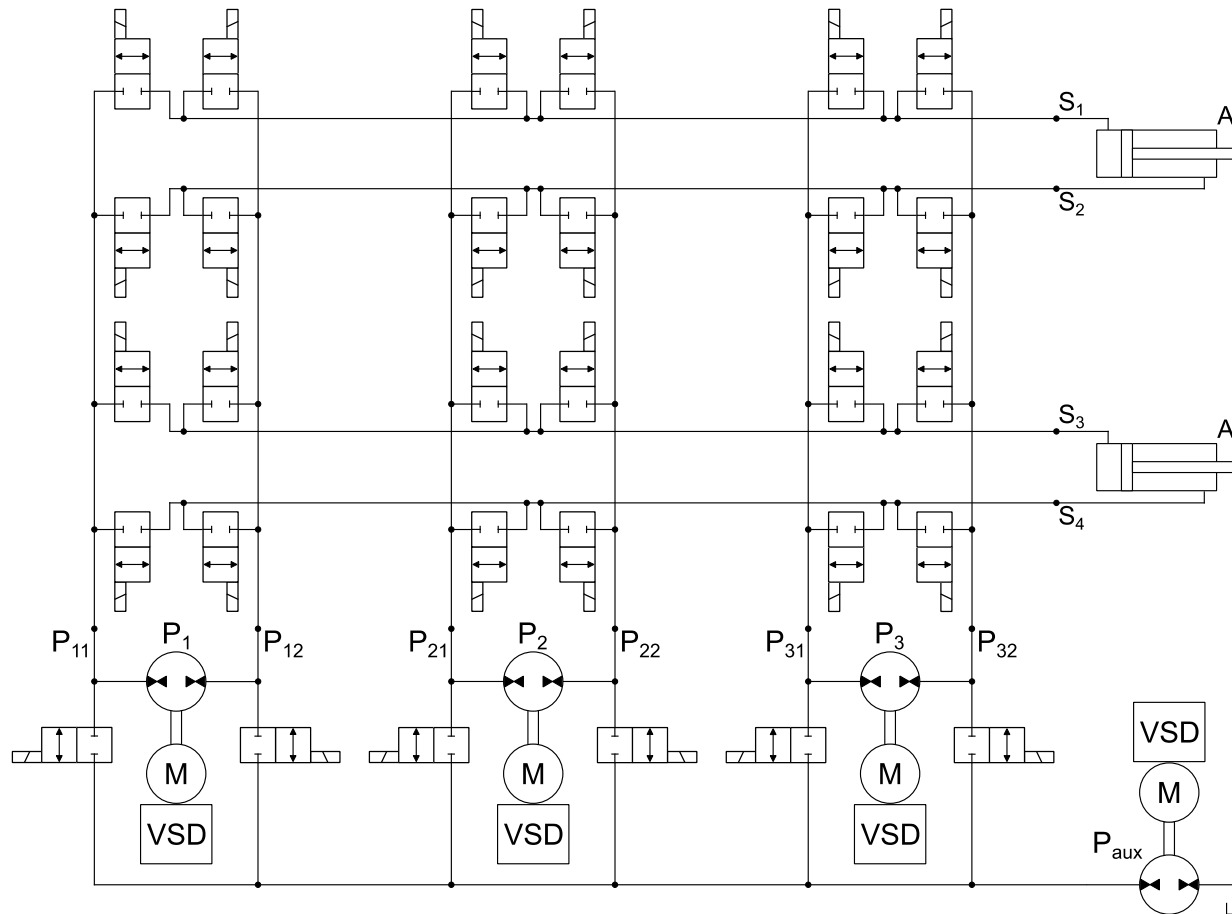
- Remove or limit the use of throttling valves
- Digital Displacement Pump (DDP) from Danfoss
 - Can be seen as 4 smaller *pumplets*
 - Speed and displacement can be controlled
- Electro-Hydrostatic Actuators (EHAs)
 - Control pump and/or electric motor



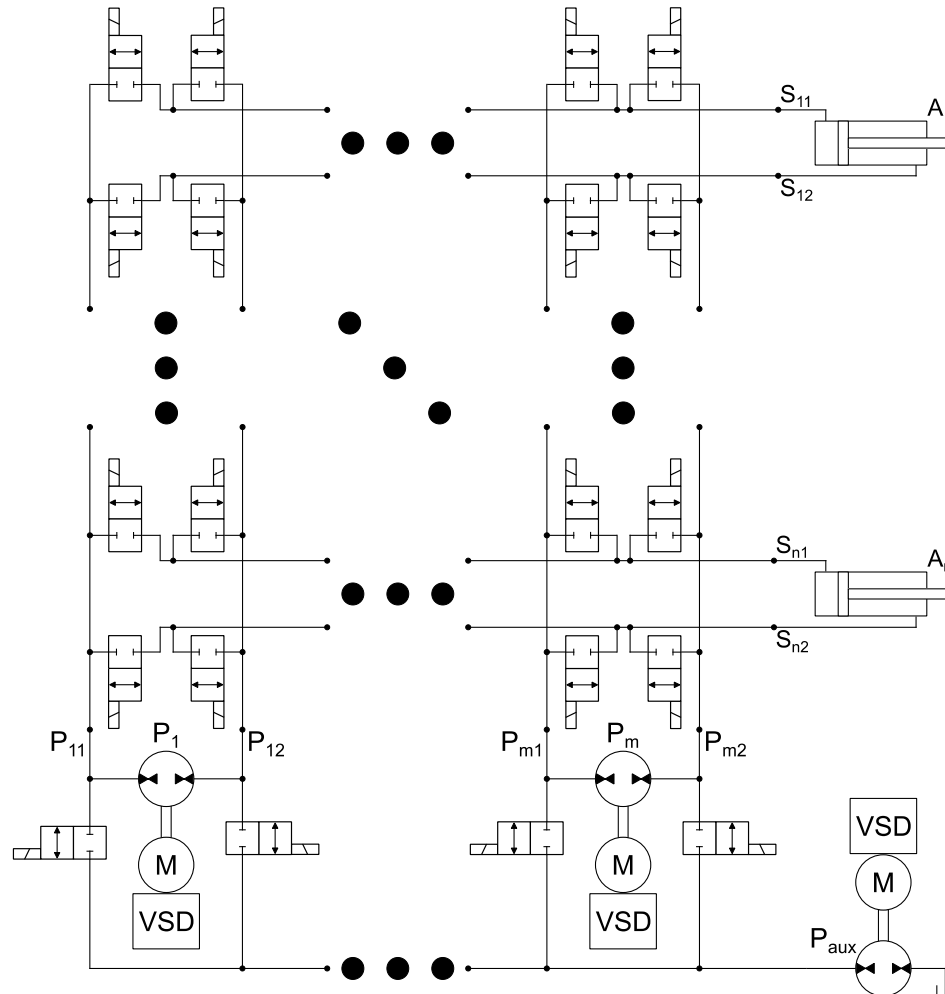
- With battery-powered vehicles we could have one EHA for each actuator
 - Each pump would have to be sized to provide the maximum flow for the actuator: total power would be higher
 - On excavators and wheel loaders the system would often operate at partial load: lower efficiency
- With multiple smaller pumps we could:
 - Select a different combination of pumps for each actuator
 - Lower total power: not all actuators should operate at maximum power at the same time
 - Control strategies can be implemented to keep the operating pumps working at high-efficiency points
 - Identical machines could reduce overall production costs



- Combine variable-speed electric motors with fixed pumps
 - VSD: variable speed drive



- Modularity: number of pumps used can change depending on number and size of actuators



- High number of components to operate simultaneously.
Considering the simple on/off valves:

$$n_v = (n_p - 1)(2 + 4n_a)$$

- 2 actuators + 4 pumps: 30 valves
 - 4 actuators + 8 pumps: 126 valves
-
- The total number of valves could be reduced by using, for example, a 4/3 directional valve
 - How to decide on the number and size of pumps?
 - How to reduce the overall number of valves?
 - How to control this system?

- Evaluate the benefits of using multiple smaller pumps with variable speed
- Dynamic programming: find the optimal solution
 - Estimate the system's maximum efficiency
 - Identify points of improvements, for example:
 - Redundant valves
 - Some loads may not require the maximum number of pumps
 - Control strategies: sequential or summative
- High number of components: evaluate the use of artificial intelligence for control



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