Comparing Electrical and Mechanical Valve Actuation in a Variable Displacement Inline Piston Pump

James Marschand
Graduate Researcher
Purdue University

Presentation Outline

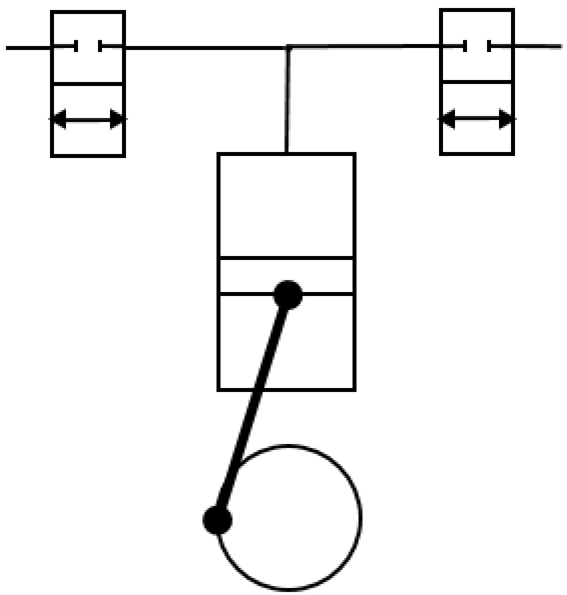
Background and Motivation

- Fluid power systems account for
  - 5% of all energy transferred in the U.S.
  - 7-8% of CO_2 emmisions in the U.S.
- Average system efficiency is only 20%
- Increasing by 5% leads to:
  - $20 billion saved
  - Reduction of 90 million tons of CO_2 emmisions
- Increasing pump efficiency increases system efficiency
- State of the art pumps experience decrease in efficiency across range of displacement

Digital Displacement Control

Digital Pump/Motor Advantages

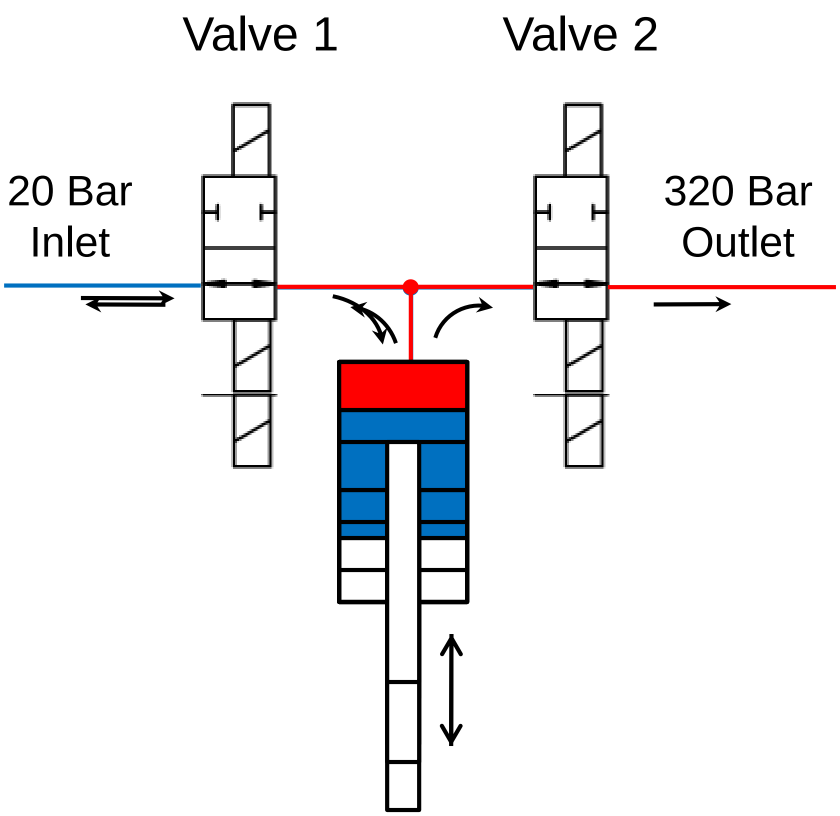
- Higher efficiency across operating range
  - Eliminates valve plate and port plate
  - Leakages scale closely with displacement
- Pumping of non-conventional fluids (water)
- Valves can open against high pressure
  - Self starting in motoring
- Freedom in operating strategies
- Lower cost
  - No need for pilot pressure
  - No electrical energy needed



Digital displacement on/off valve placement

Digital Displacement Control

- Flow Diverting
  - Excess flow taken into the chamber is diverted back to the low pressure port
- Flow Limiting
  - Amount of flow taken into the chamber is limited to the desired flow
- Sequential (Diverting or Limiting)
  - Individual cylinders are operated at full or zero displacement



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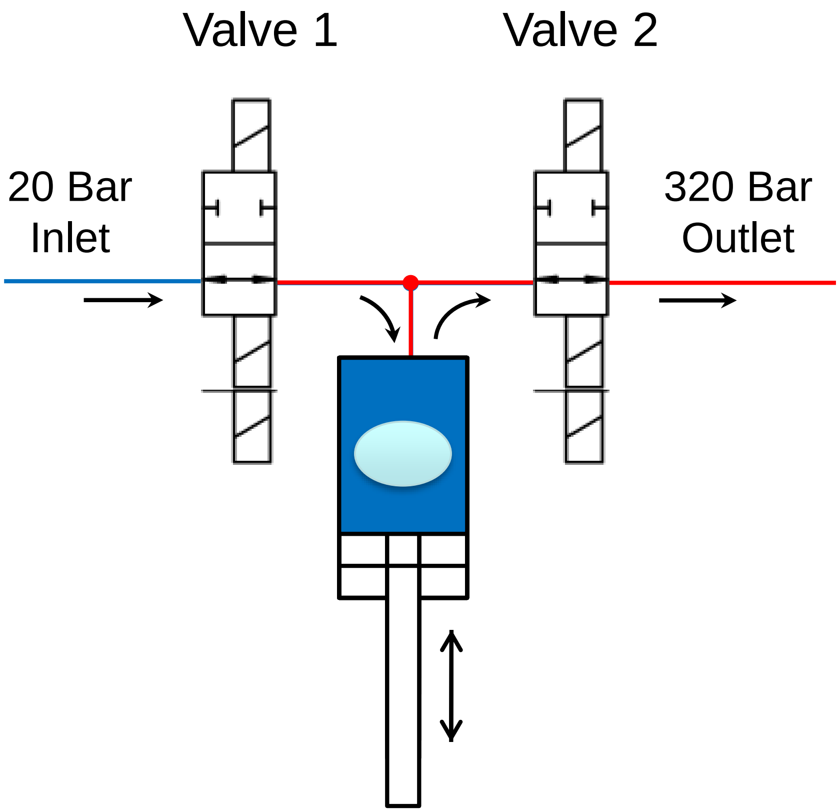
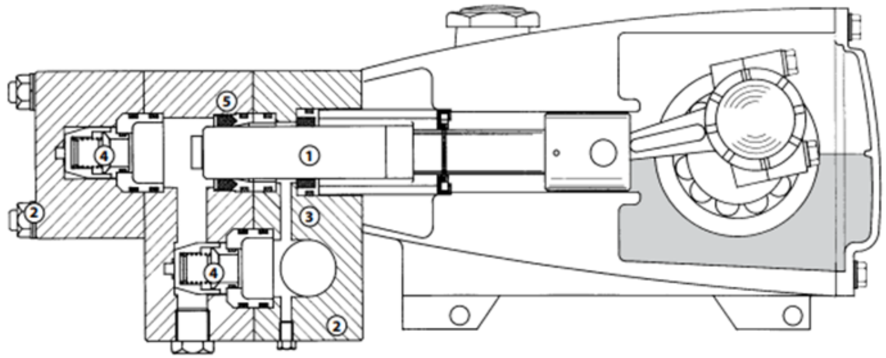


Digital Displacement Control

Prototype Design

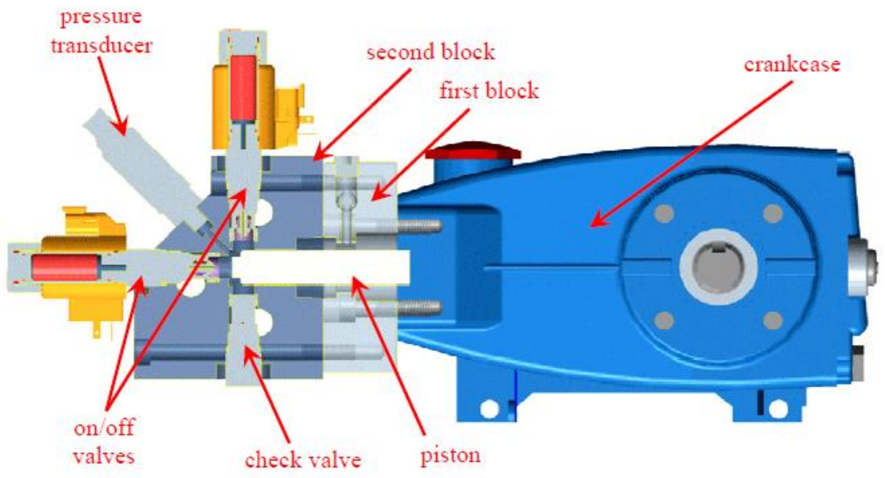
- Base unit- CAT Model 1861
  - 3-piston inline pump
  - Fixed displacement
  - High pressure water applications
  - Modular design
  - Lip seals
- Two seperate prototypes
  - Electrically actuated valves (EAV)
  - Mechanically actuated valves (MAV)
- New block
  - Housing for on/off valves

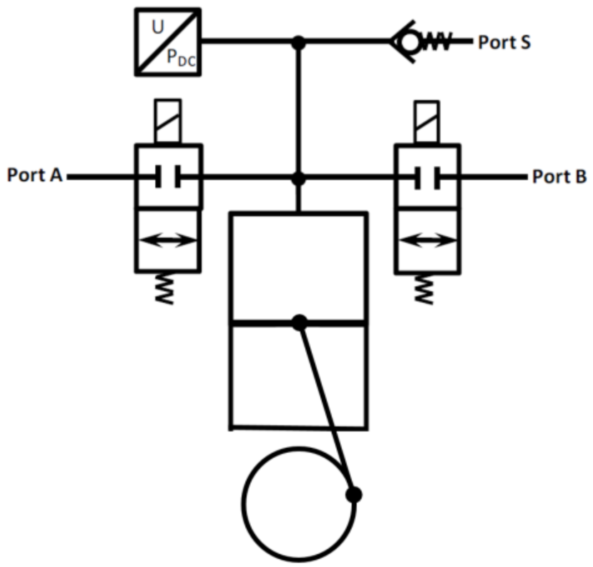


CAT Model 1861 base model
(CAT Pumps)

Electically Actuated Prototype

- Solenoid operated on/off valves
  - Valve opening area limited by solenoids
- Requires sensors and controls for operation
- Low repeatability

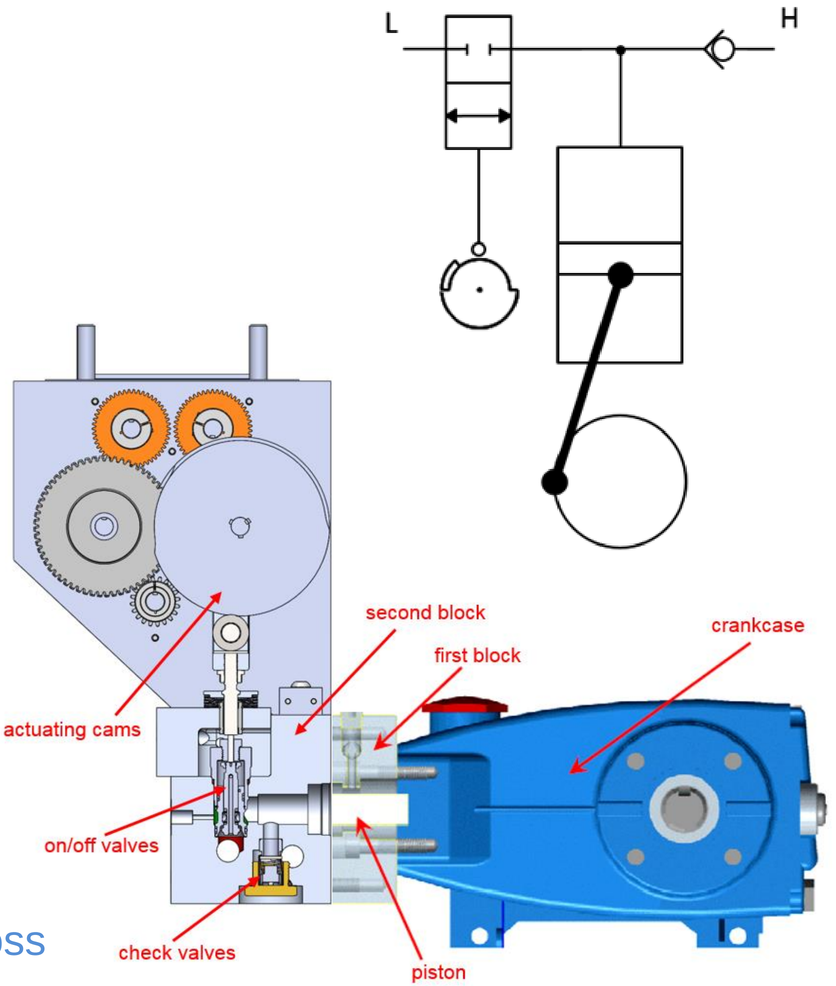




Cross section of EAV block (left), Schematic of internal ports of the EAV (right) (Holland 2012)

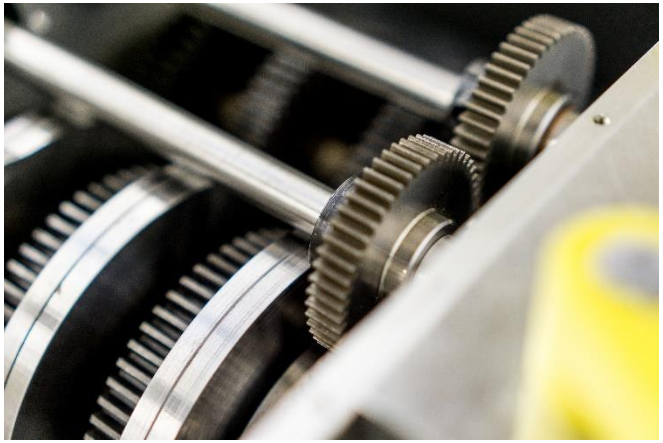
Mechanically Actuated Prototype

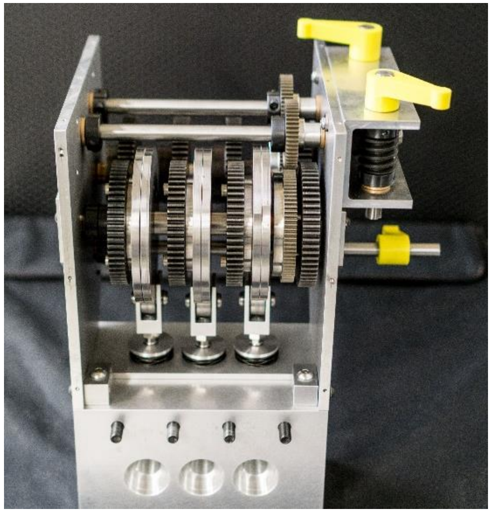
- Cam actuated valves
  - Half masking cams
  - Dual input planetary gear system
- Outlet valve replaced with check valve
- Simple hand control
  - Adjustment of pressure and displacement

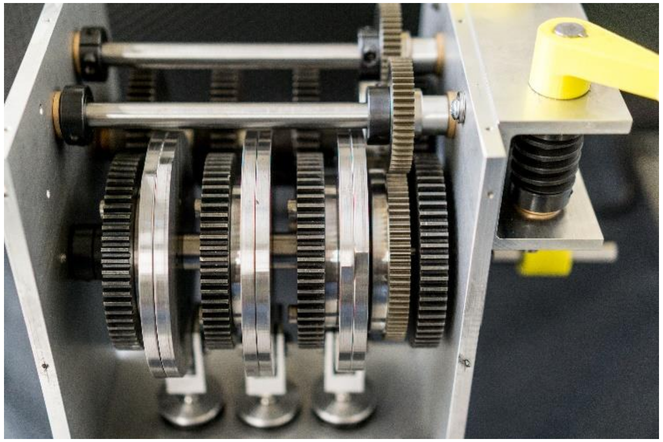


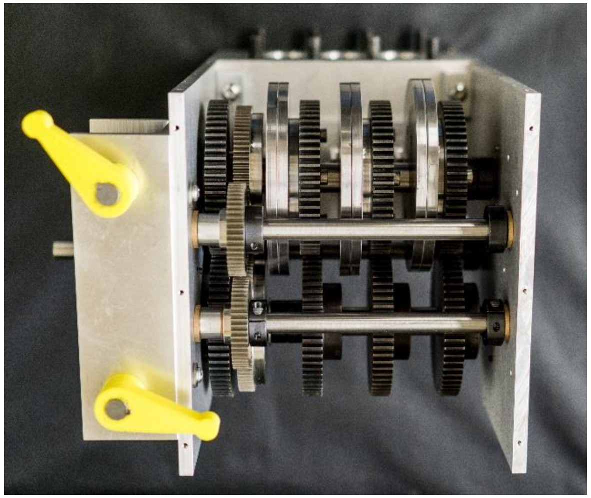
Schematic of internal ports of the MAV (Top), Cross Section of MAV block (bottom) (Helmus 2017)

Mechanically Actuated Prototype

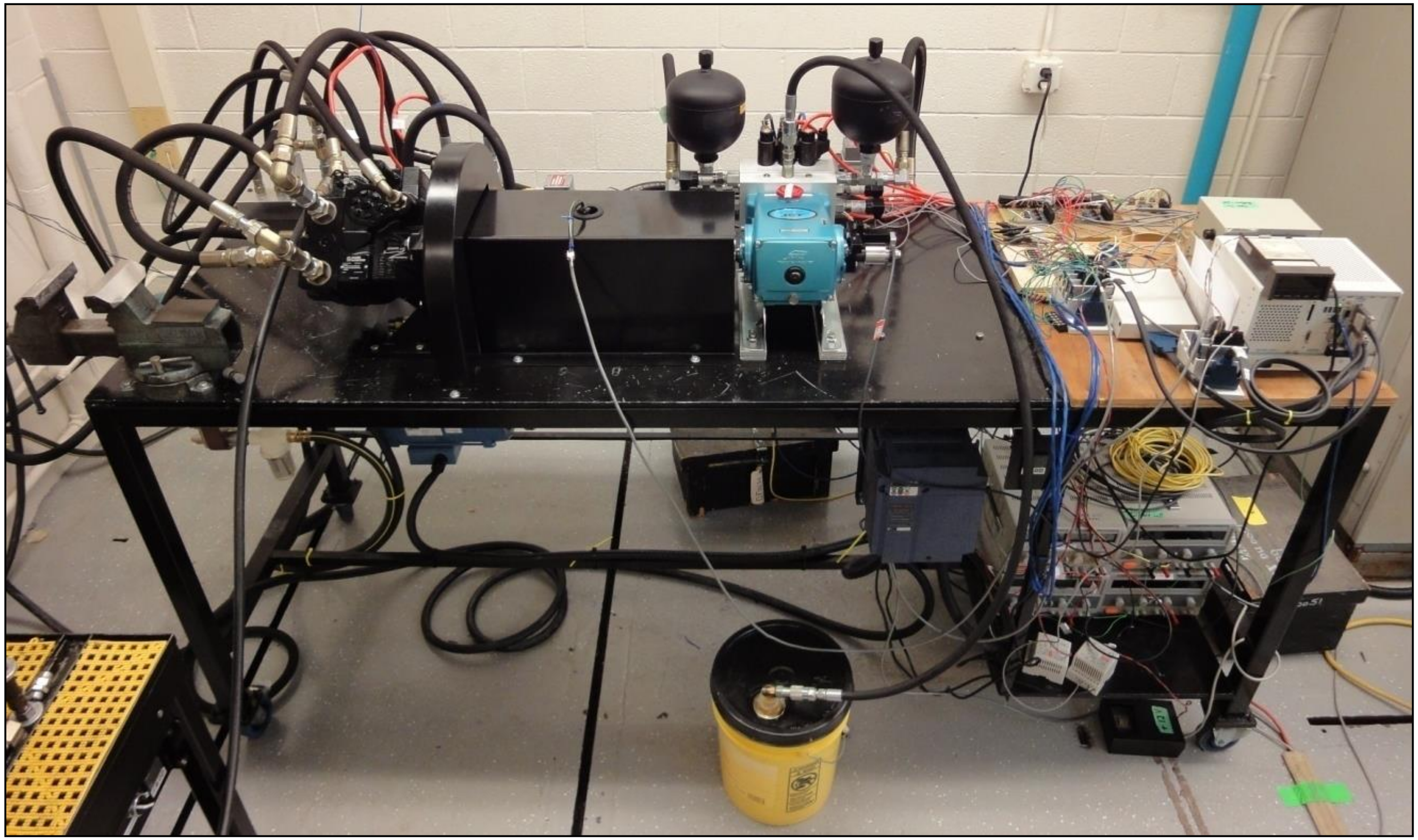








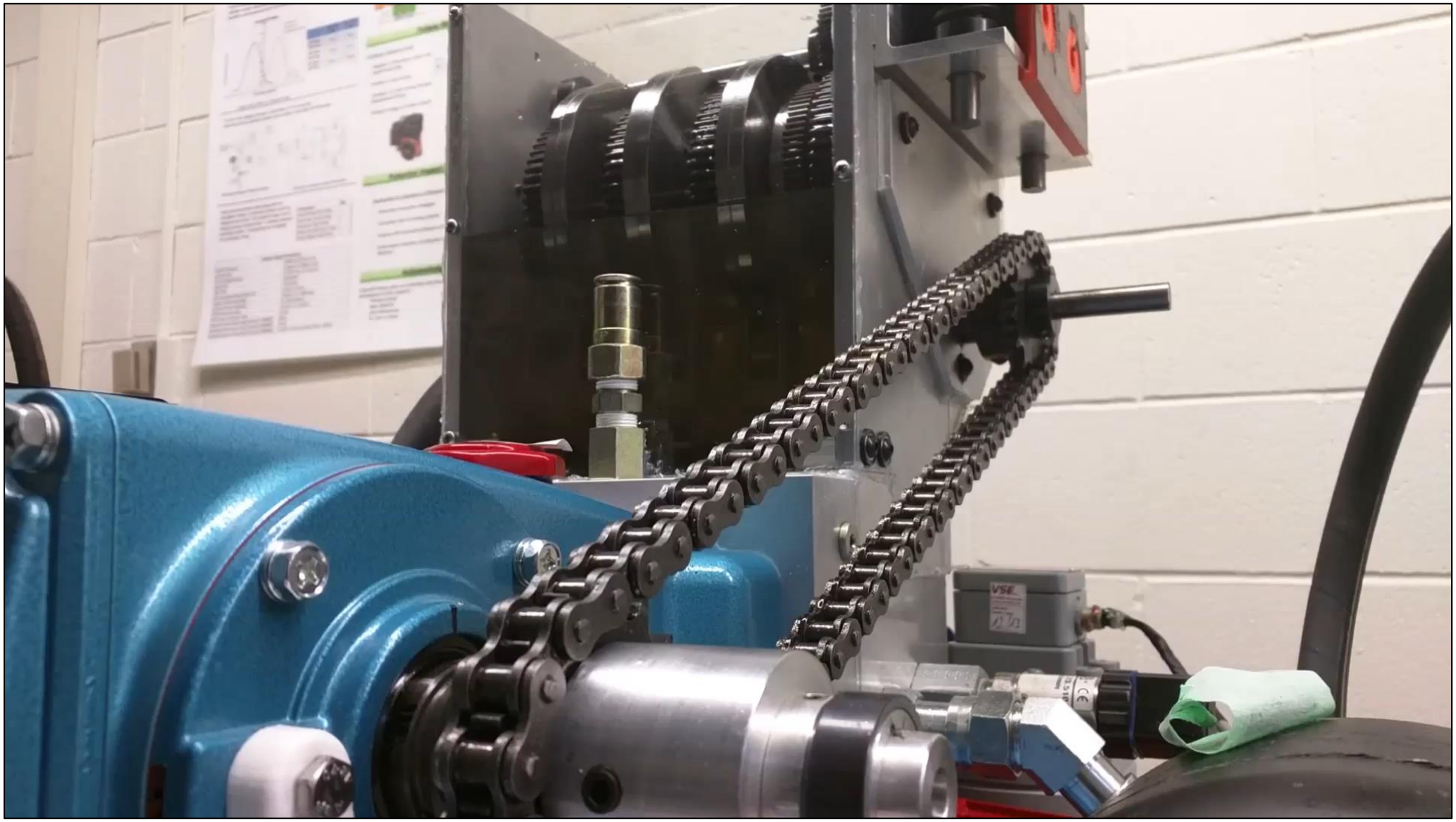
Experimental Testing



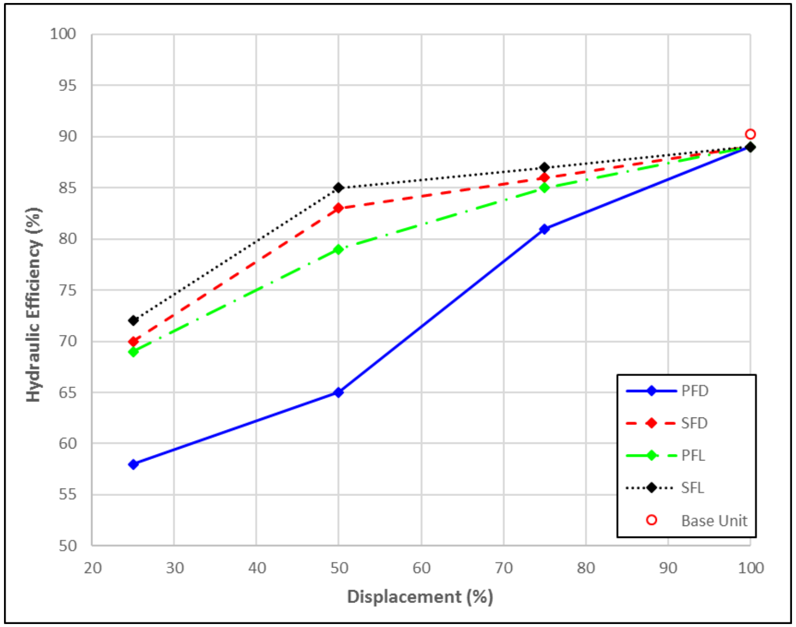
Multi-piston digital pump/motor test stand

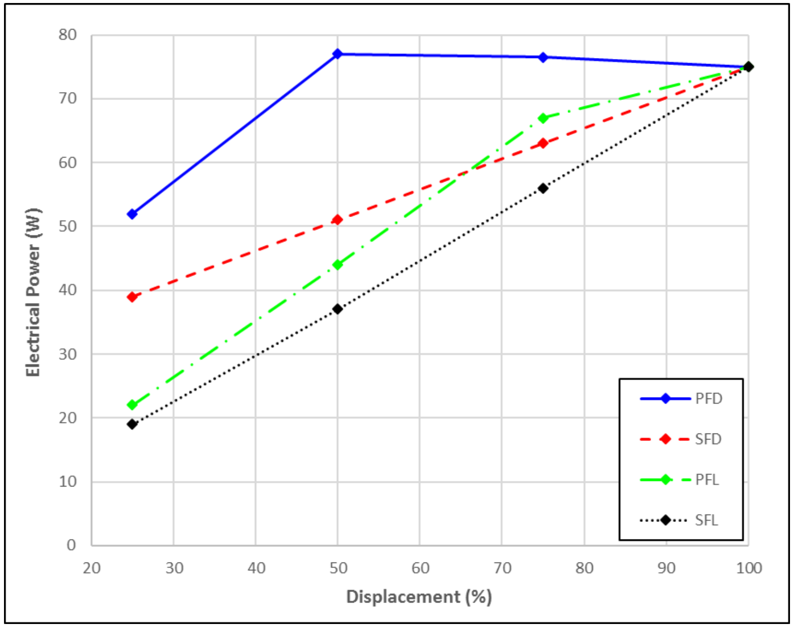
- 3-piston digital pump/motor
- On/off valves for each piston
- In chamber pressure transducers
- Inlet and outlet pressure and flow sensors
- Two accumulators

Experimental Testing



Results for Electrical Actuation

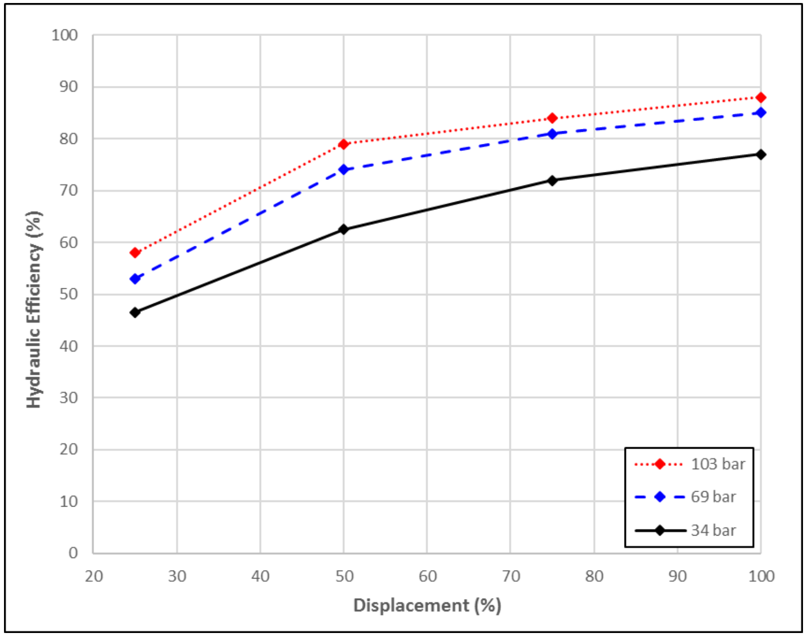


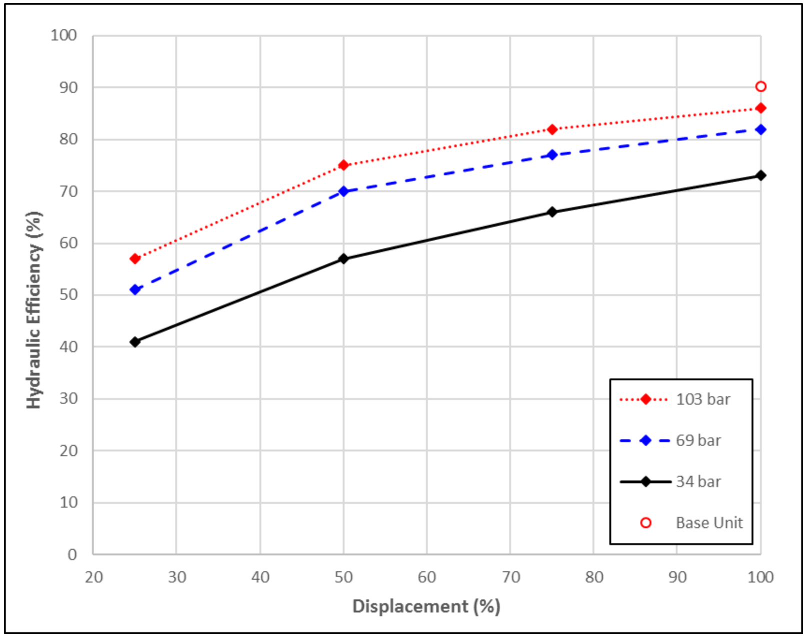


Overall hydraulic efficiency for pumping, at 103 bar, 500rpm (left), electrical energy requirements, pumping, 103 bar, 500 rpm (right) (Holland 2012)

- Each operating strategy was tested
- Inverse relationship between electrical power consumption and hydraulic efficiency
- Efficiency does not drop below 45% in worse operating conditions

Results for Mechanical Actuation



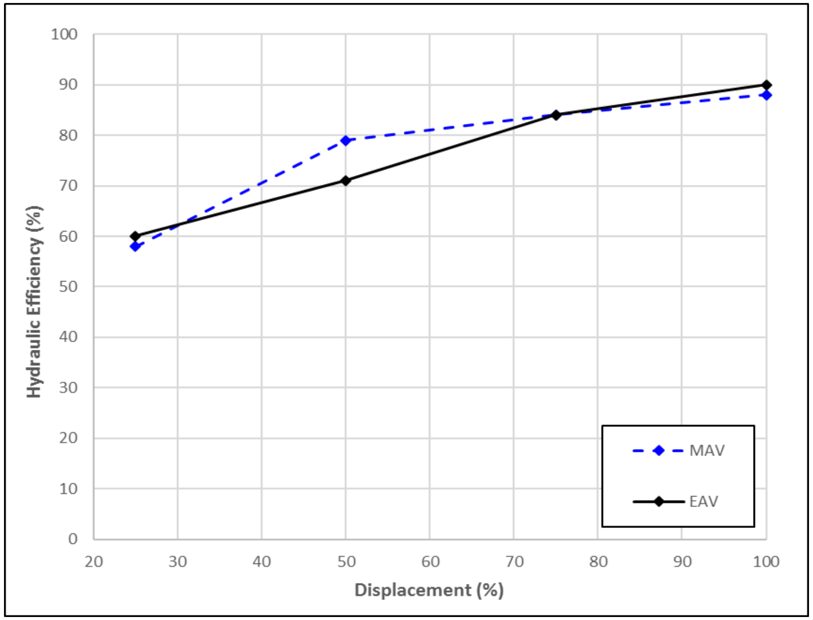


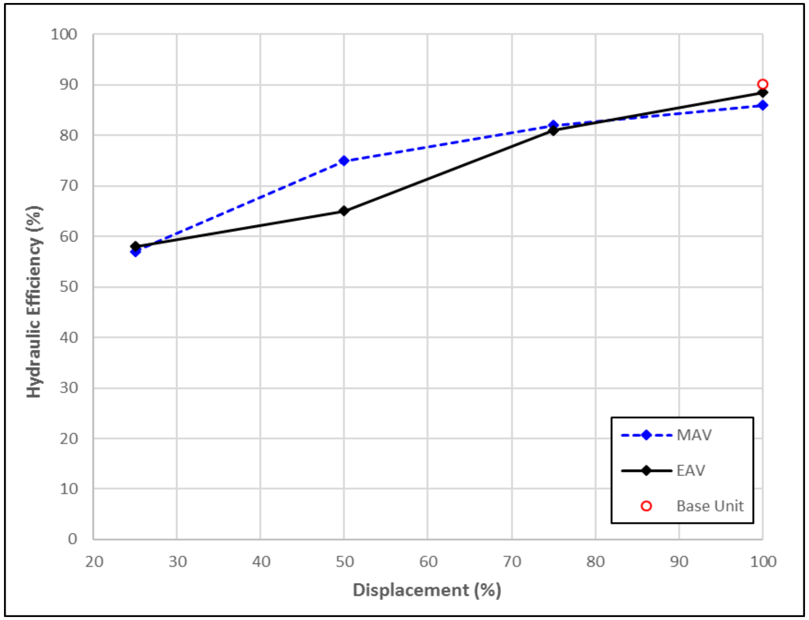
Overall hydraulic efficiency for pumping at 300rpm (left), 500rpm (right)

- Partial flow diverting only operating strategy tested
- Efficiency does not fall below 40%

Comparison of Actuation Techniques

- Both prototypes use the same valves
- Comparable efficiency across entire range
- Variability where timing is most critical
  - Proves increased repeatability of mechanical actuation





Overall hydraulic efficiency for both prototypes, 300rpm, 103bar (left), 500rpm 103 bar (right)

Conclusions and Future Work

- Both actuation techniques provide an increase in efficiency for the lower displacement ranges
- Mechanical actuation is the superior techinique
  - Similar efficiency
  - No sensors or controls
  - No electrical energy consumption
- Potential to improve
  - Change to radial piston orientation to use one central cam for each piston
  - Increase cam diameter to minimize cam friction
  - Increase valve size to reduce valve losses

Thank you for your attention!

Contact:

James Marschand

Purdue University

jmarsch@purdue.edu