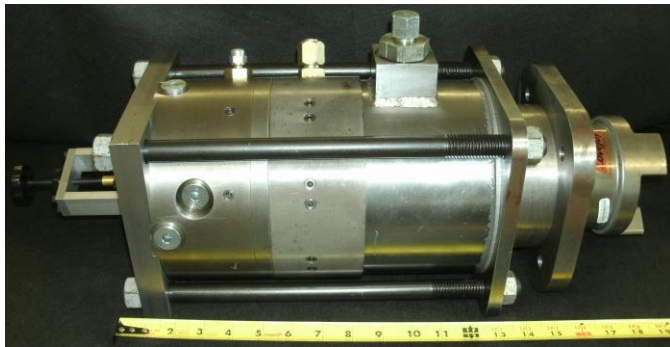




High Efficiency Hydraulic Pump-Motors Employing Partial Stroke Piston Pressurization



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Dr. Thomas Chase
Dr. Perry Li





Hydraulic power - applications



Image taken from: https://www.caseih.com/northamerica/en-us/products-skid-steers/wheeled_skid_steer



Image taken from: <https://www.bobcat.com/loaders/compact-track-loaders/models/t590/photos-videos#lightbox-t590-m2-grapple-hay>



Existing Technology - Artemis Digital Displacement™

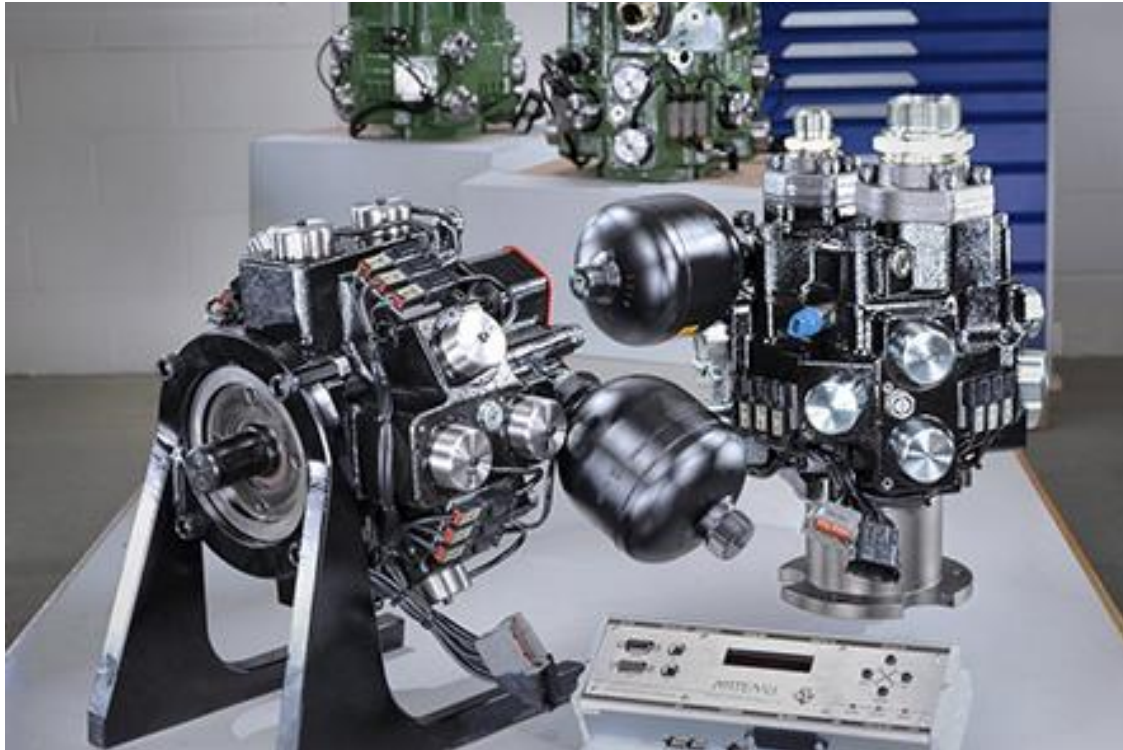


Image taken from: <http://www.artemisip.com/our-products/industrial-hydraulic-pump>

- The most efficient axial piston pump on the market
- Achieve high efficiency at low displacements
- Two electromagnetic valves per piston
- Electronic sensors and controls



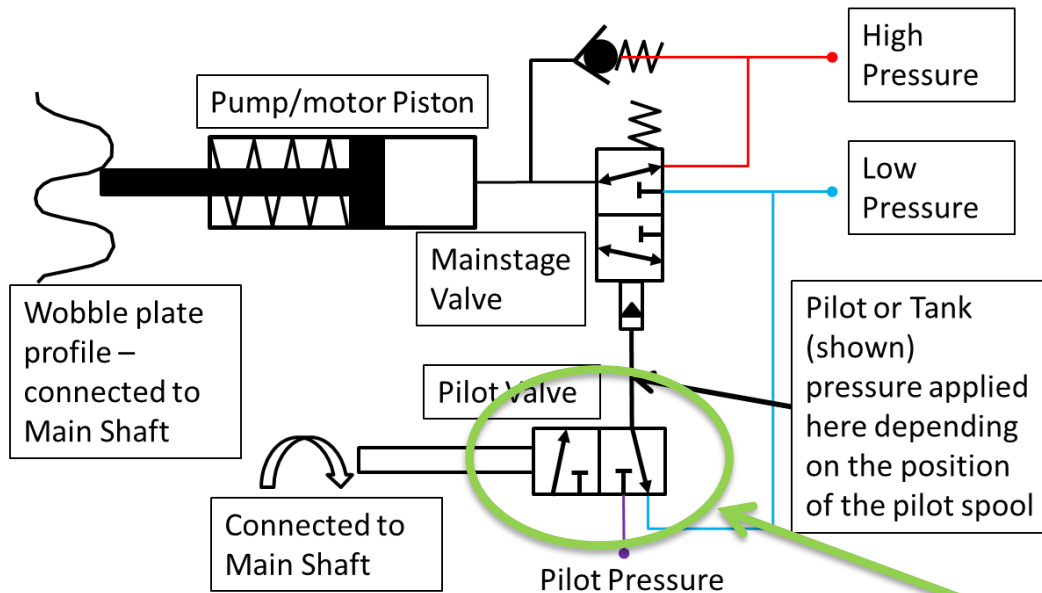
Our approach: Hydro-Mechanical Control



- **Robust:** No solenoids/wires/power electronics to fail on each piston
- **Low cost:** No controllers for individual pistons
- **Simple:** Only one control input needed
- **Hydromechanical power:** No need for electrical supply
- **Fast and repeatable timing:** Speed scales up with pump speed

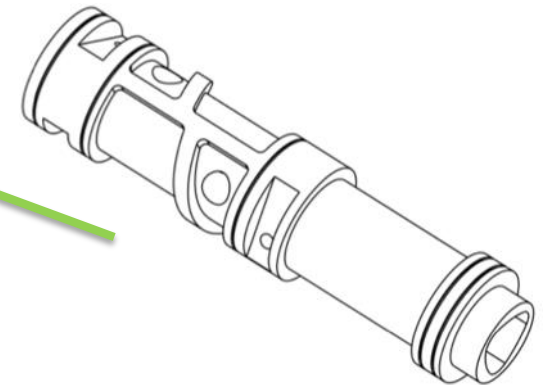


Concept



Two stage valving:

- 2D Rotary valve - pilot stage
- Spool valve - main stage

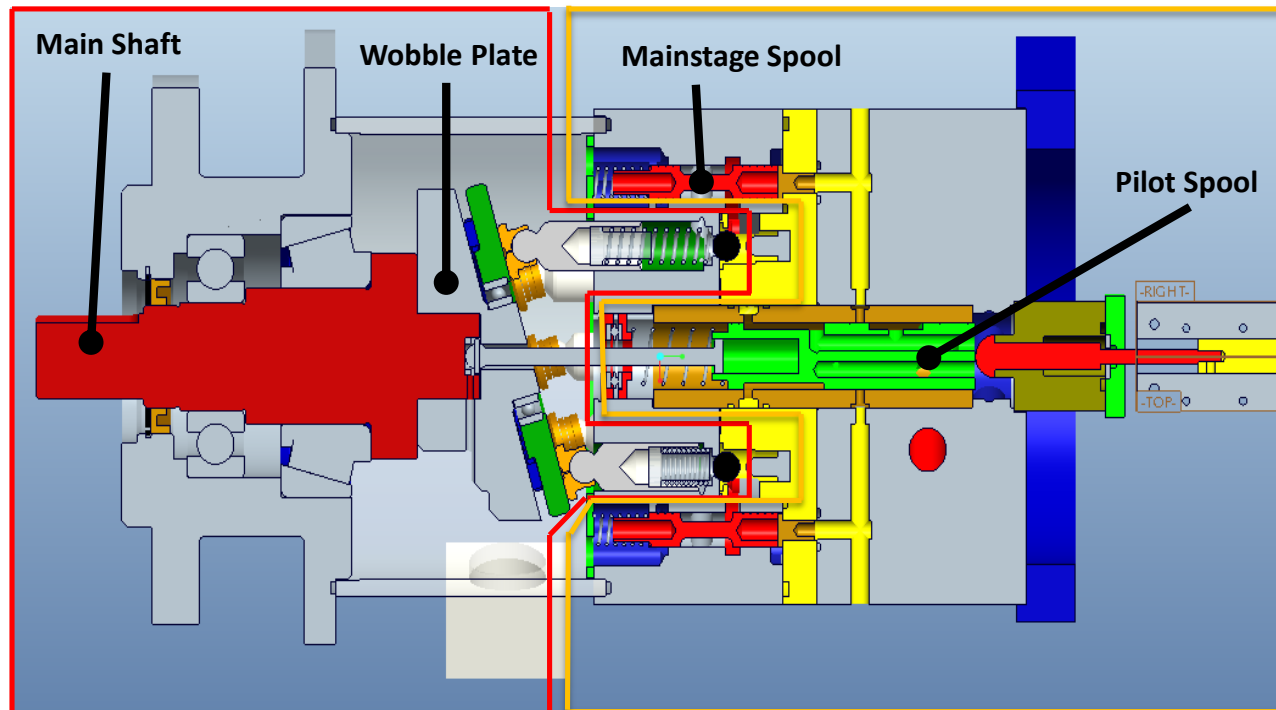


Pilot stage is a 2 Degree-of-freedom valve:

- Rotation with shaft
- Translation adjusts displacement



Cutaway CAD model



**Wobble Plate
Pump/Motor**

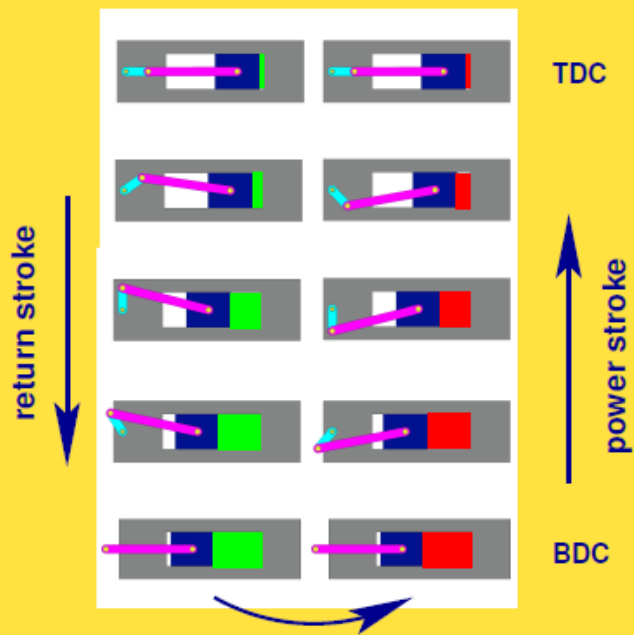
PSPP Controller



What is Partial Stroke Piston Pressurization (PSPP)?

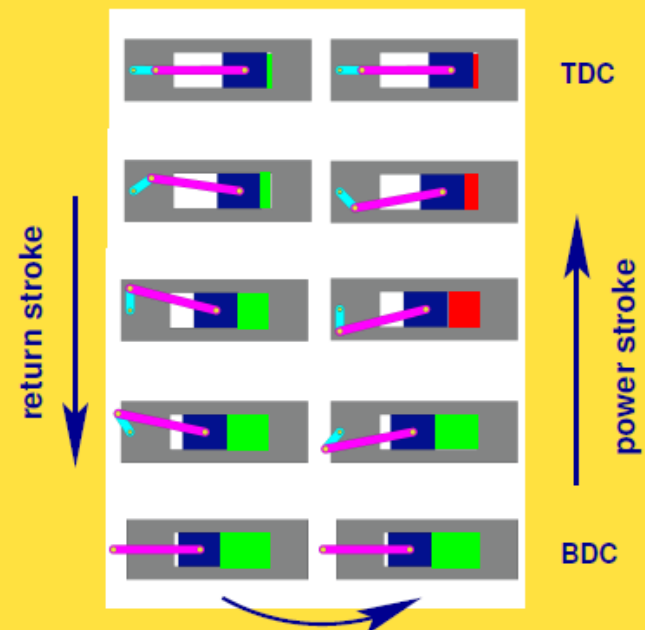
Variable Displacement Swashplate:
Piston is subjected to high pressure for the entire power stroke

■ : low pressure ■ : high pressure

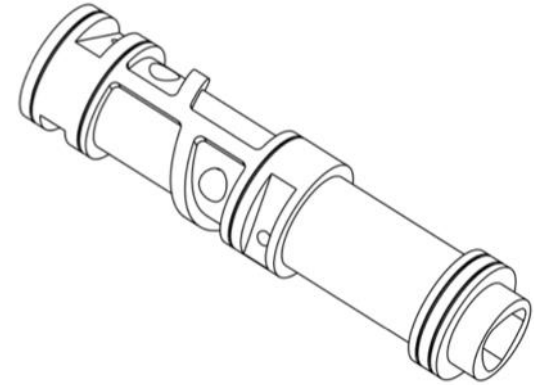
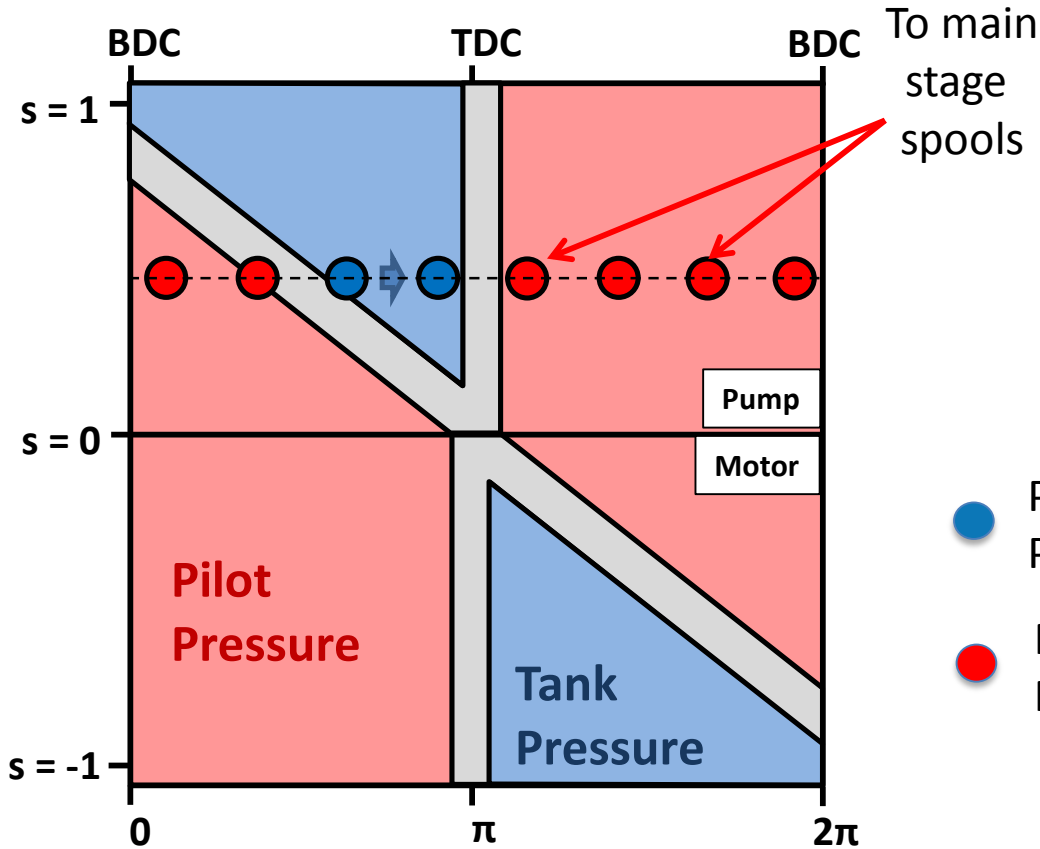


PSPP:
Piston is subjected to high pressure for only a fraction of the power stroke

■ : low pressure ■ : high pressure



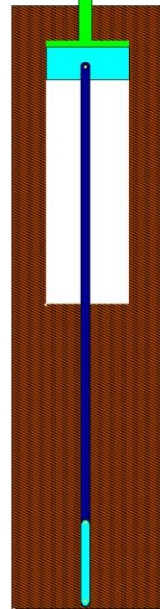
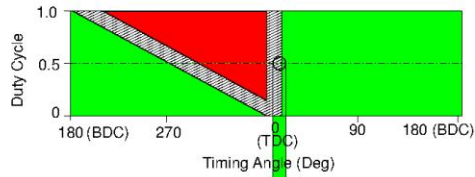
Pilot Spool Profile



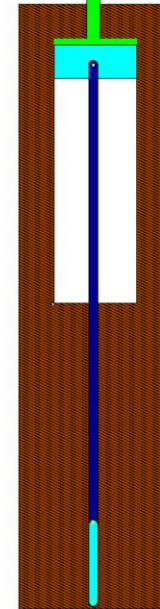
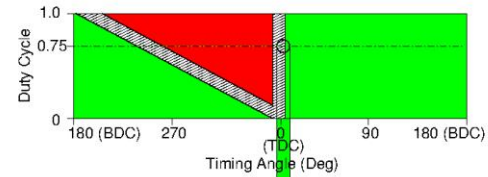
- Pilot = P_{tank} ,
Piston enabled (to high P)
- Pilot = P_{pilot} ,
Piston disabled (to tank)



Animation



$S = 0.5$



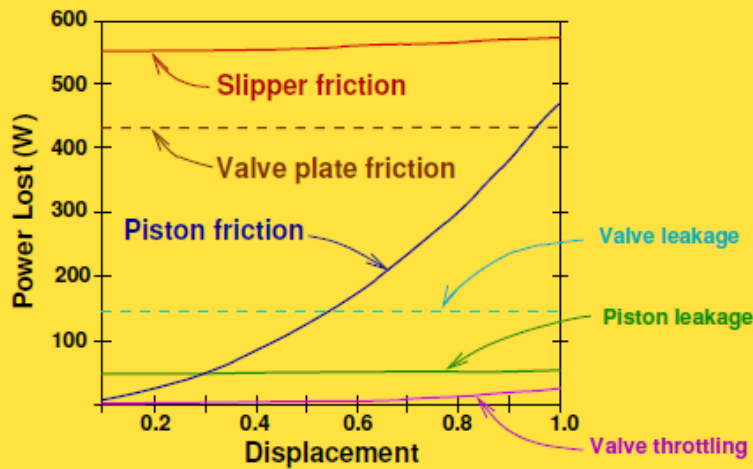
$S = 0.75$



Why Is PSPP More Efficient?

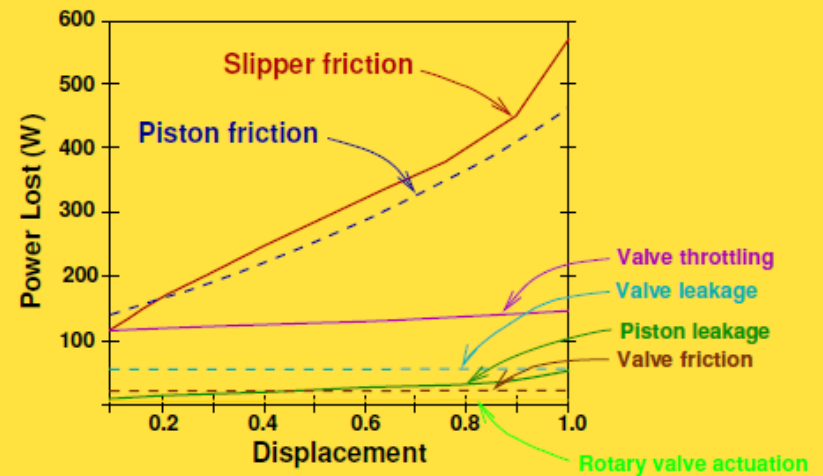
Simulated losses in 48 cc pumps operating at 200 bar and 1800 RPM:

Swashplate pump



The two highest losses are slipper and valve plate friction

PSPP pump



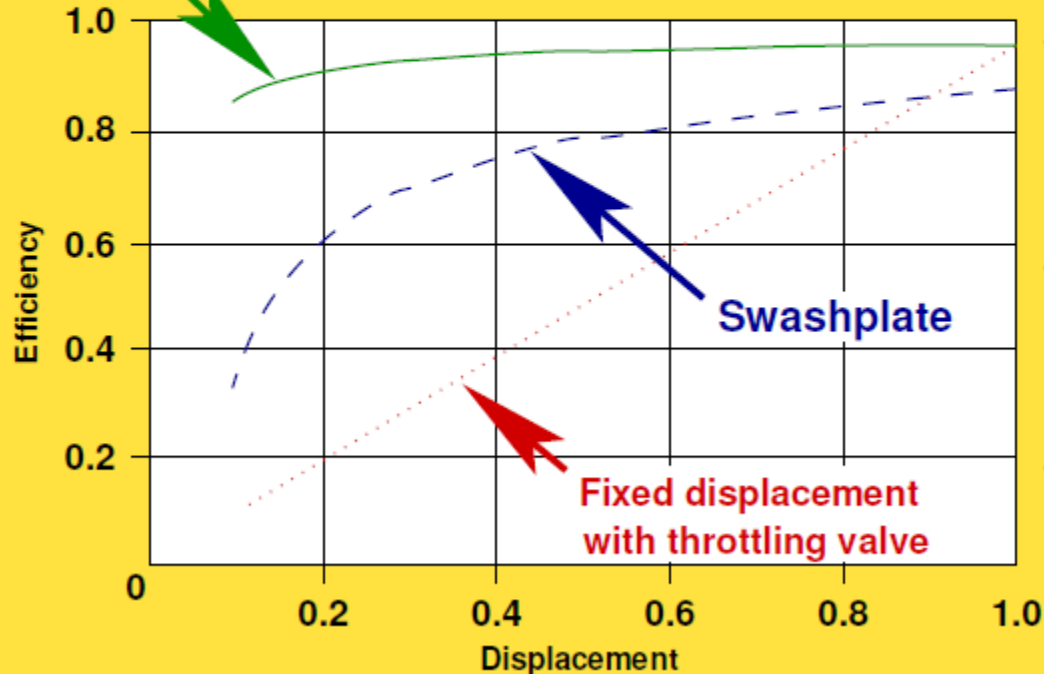
** The valve plate is eliminated
* Slipper friction scales with displacement*



Technical Payoffs:

PSPP

Approximate Efficiencies
of Different Pump Technologies



+ Saves energy!
(Fluid power accounts for ~3% of all domestic energy usage)

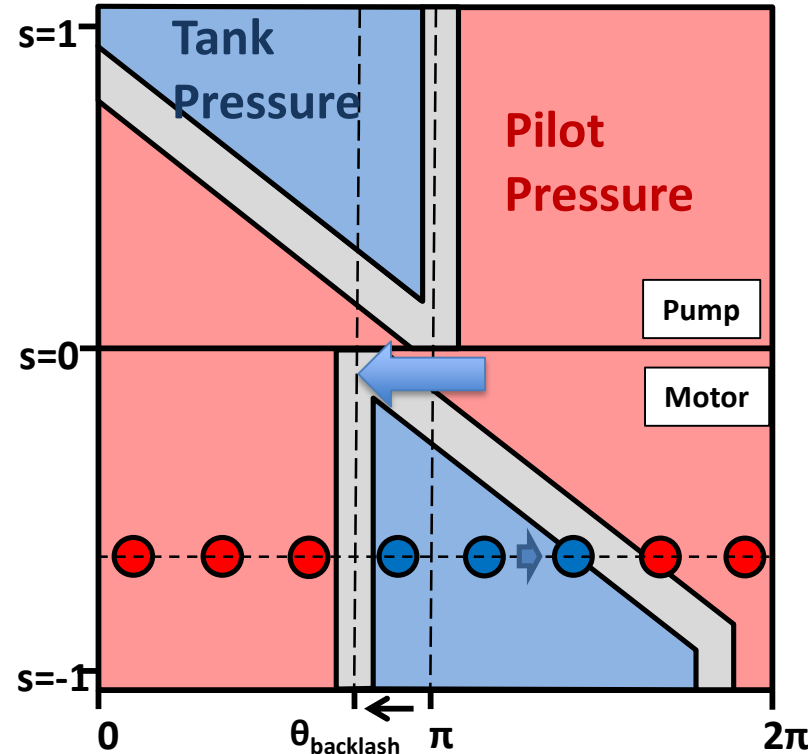
+ Many hydraulic systems are run at partial power most of the time

+ Other system components (especially cooling system) can be downsized



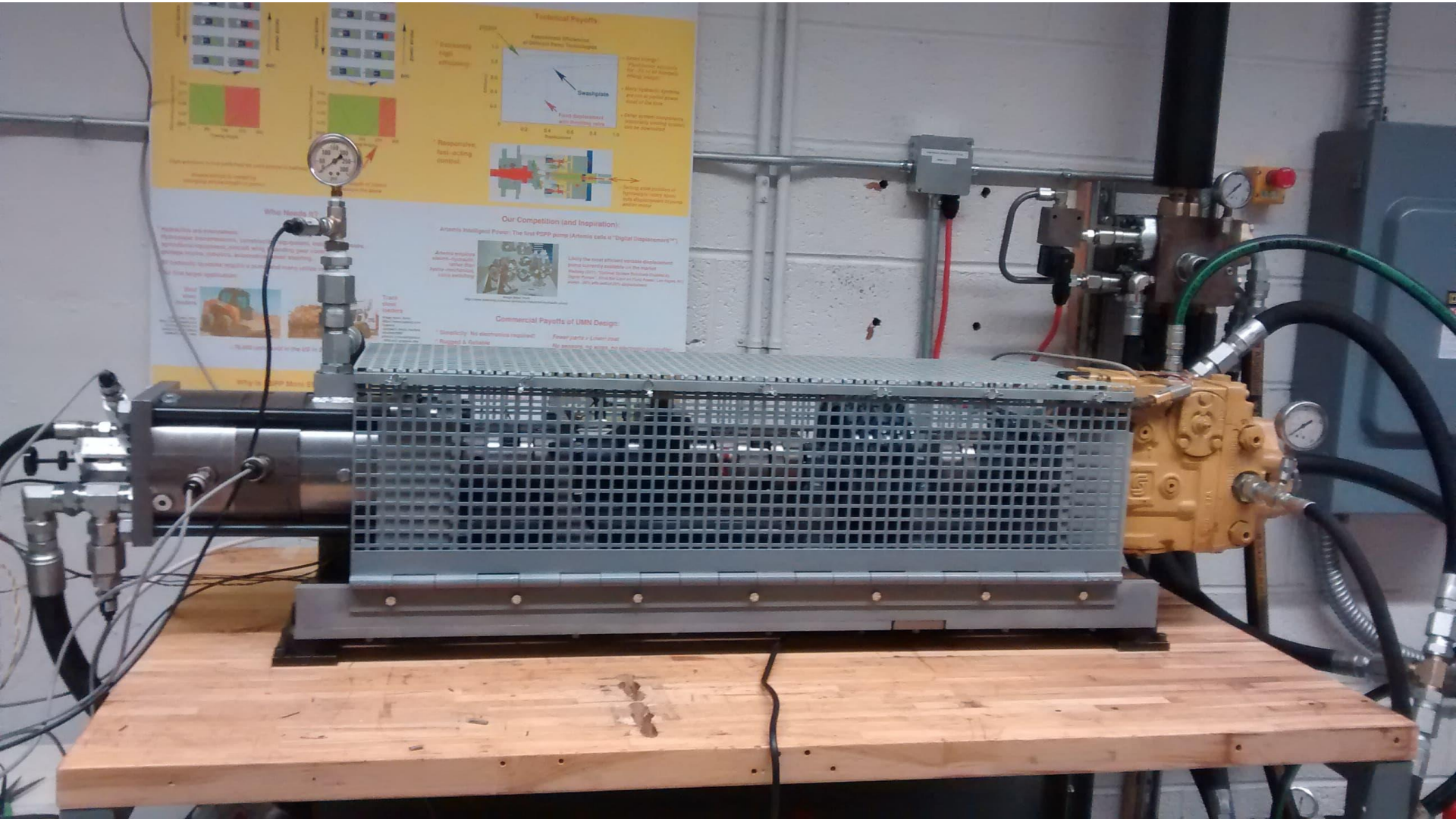
Pre-compression backlash

- Shift motor timing so the transition between low and high pressure in the piston chambers precedes TDC position
 - add backlash between shaft and wobble plate



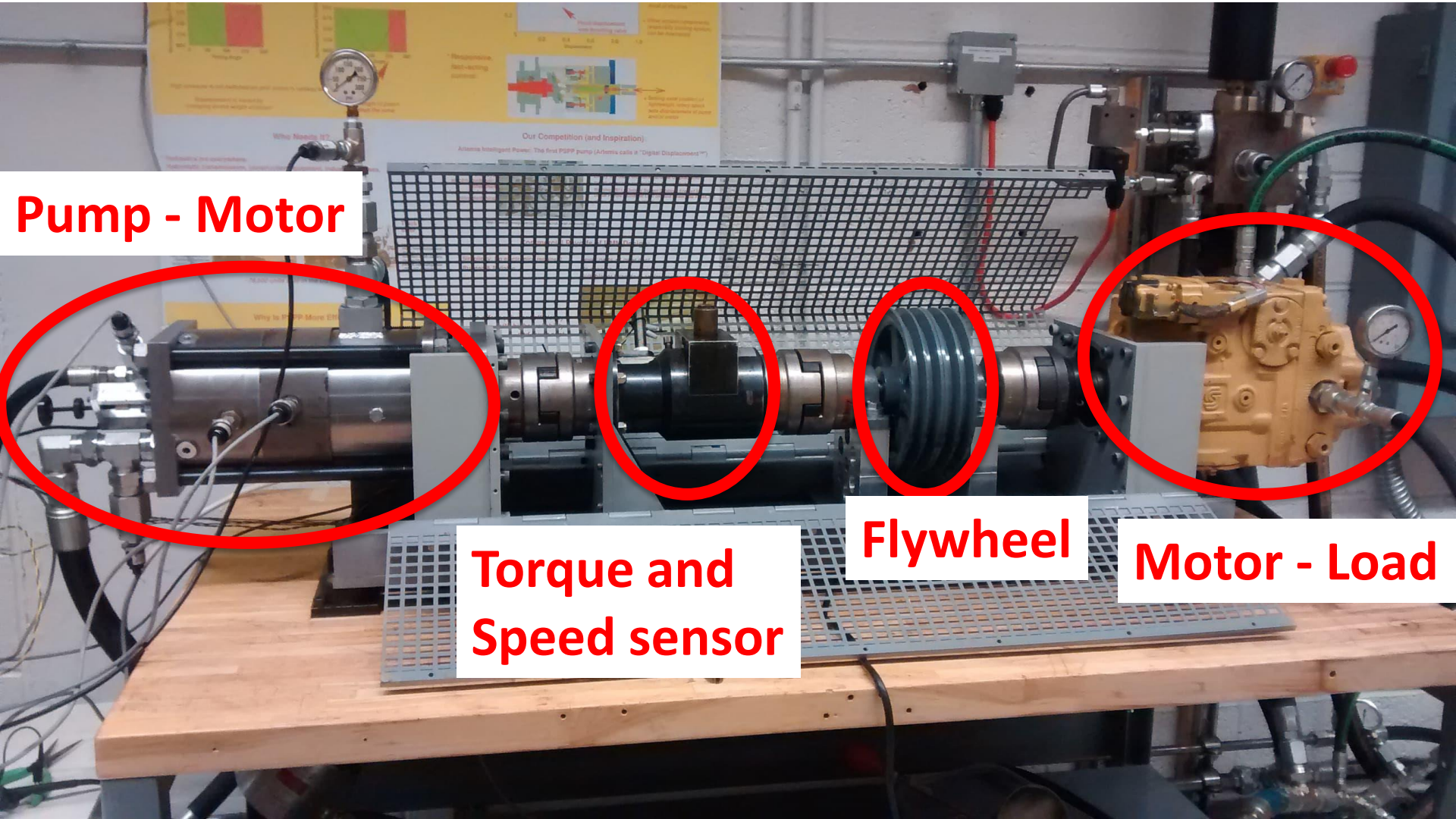


Test Stand





Test Stand



Pump - Motor

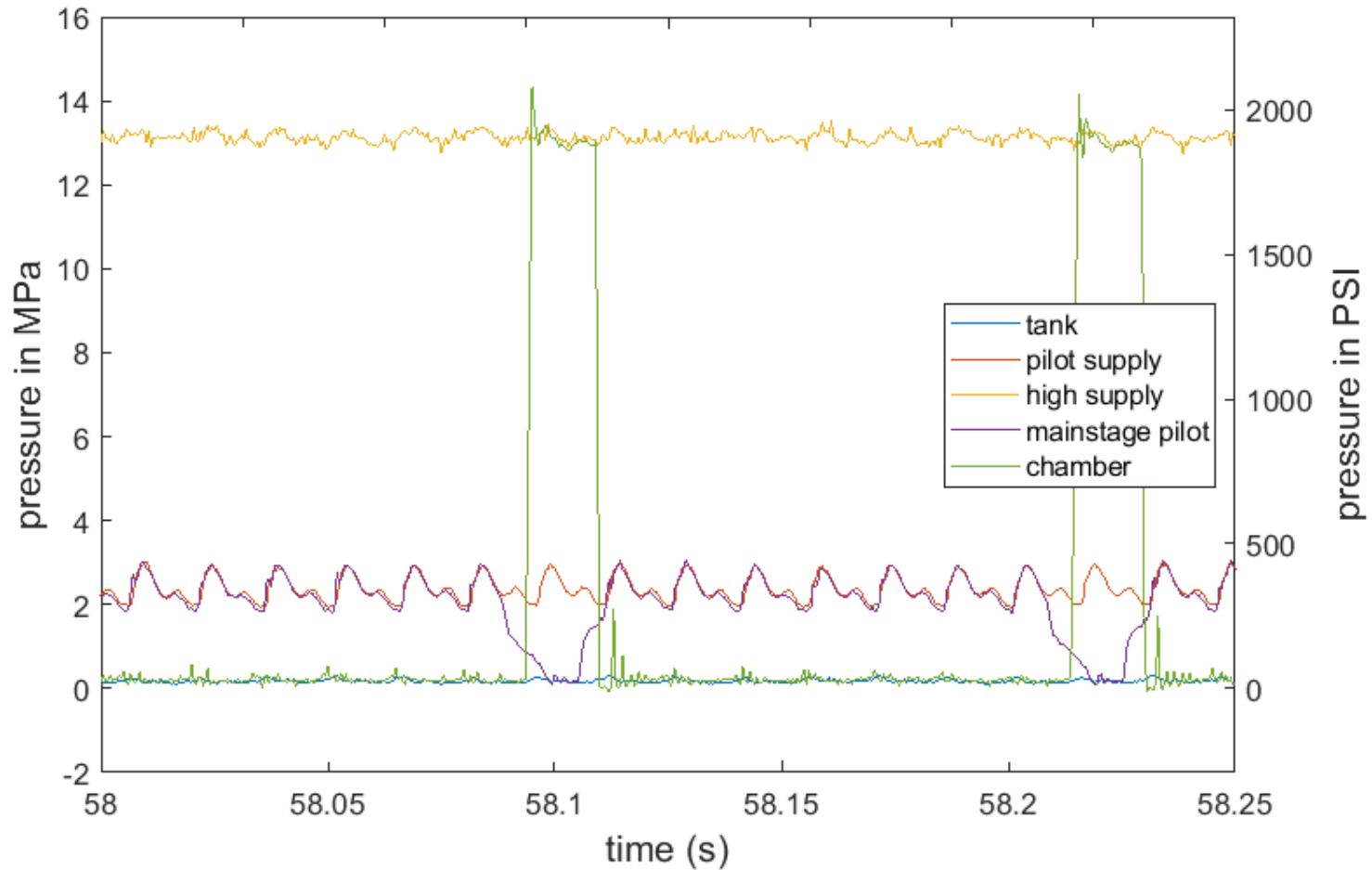
Torque and Speed sensor

Flywheel

Motor - Load

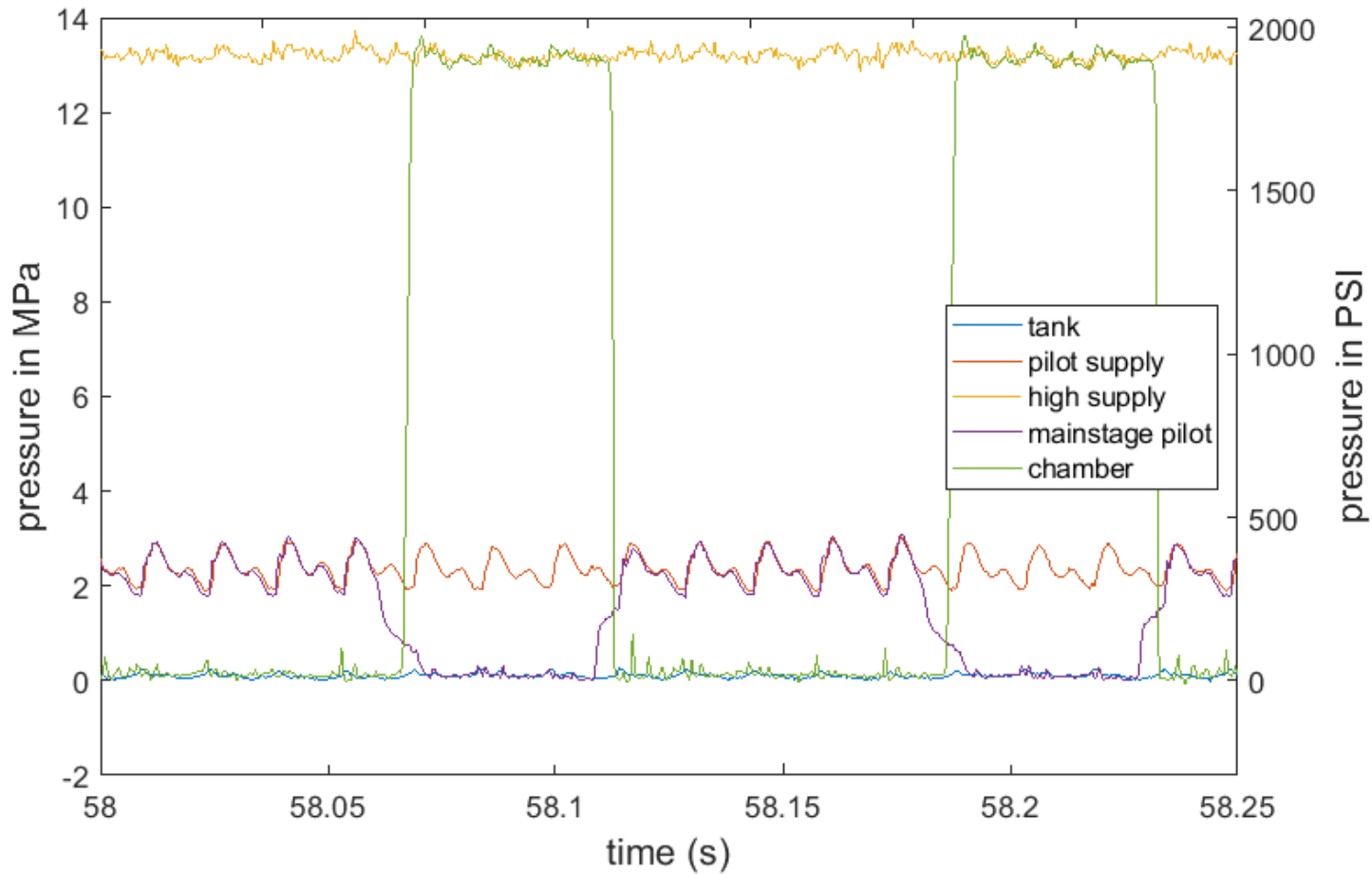


Results – pressure traces at low displacement $s \approx 0.15$



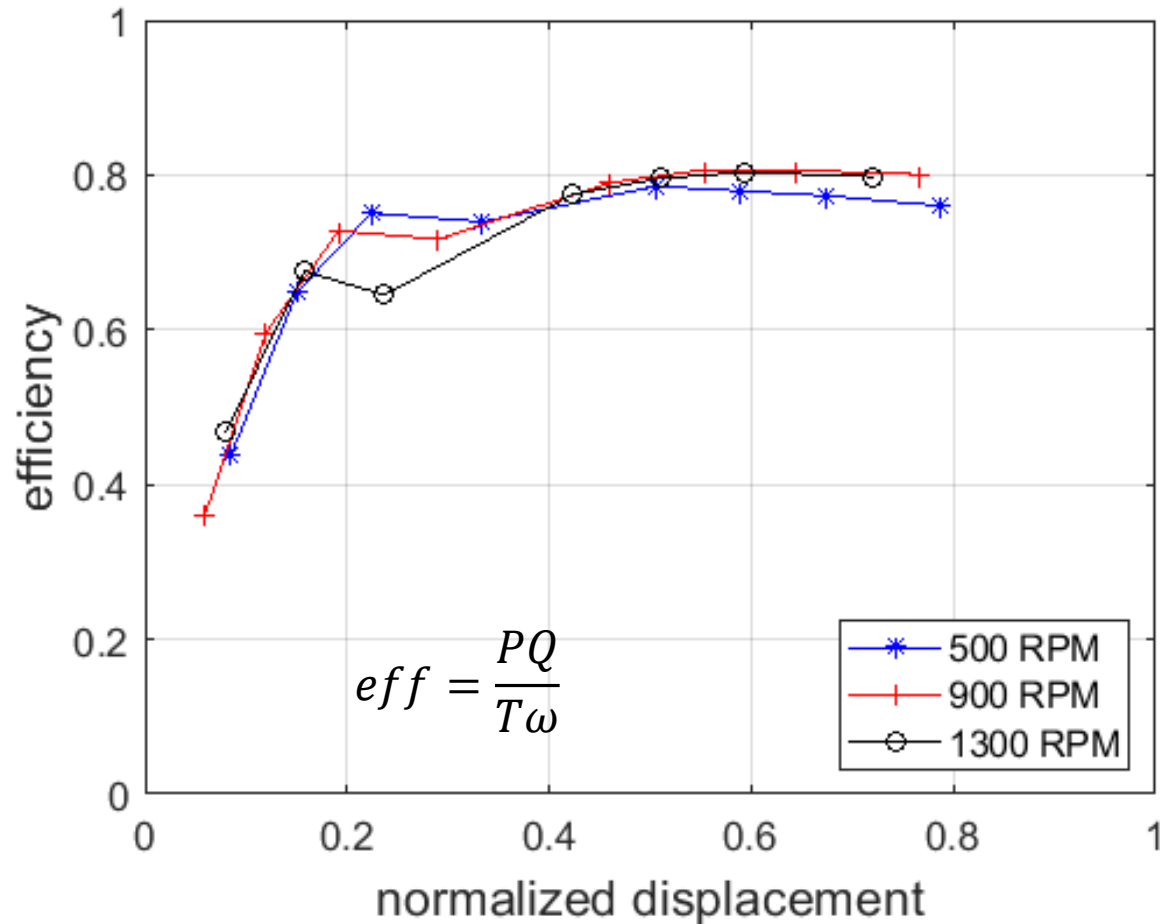


Results – pressure traces at high displacement $s \approx 0.86$



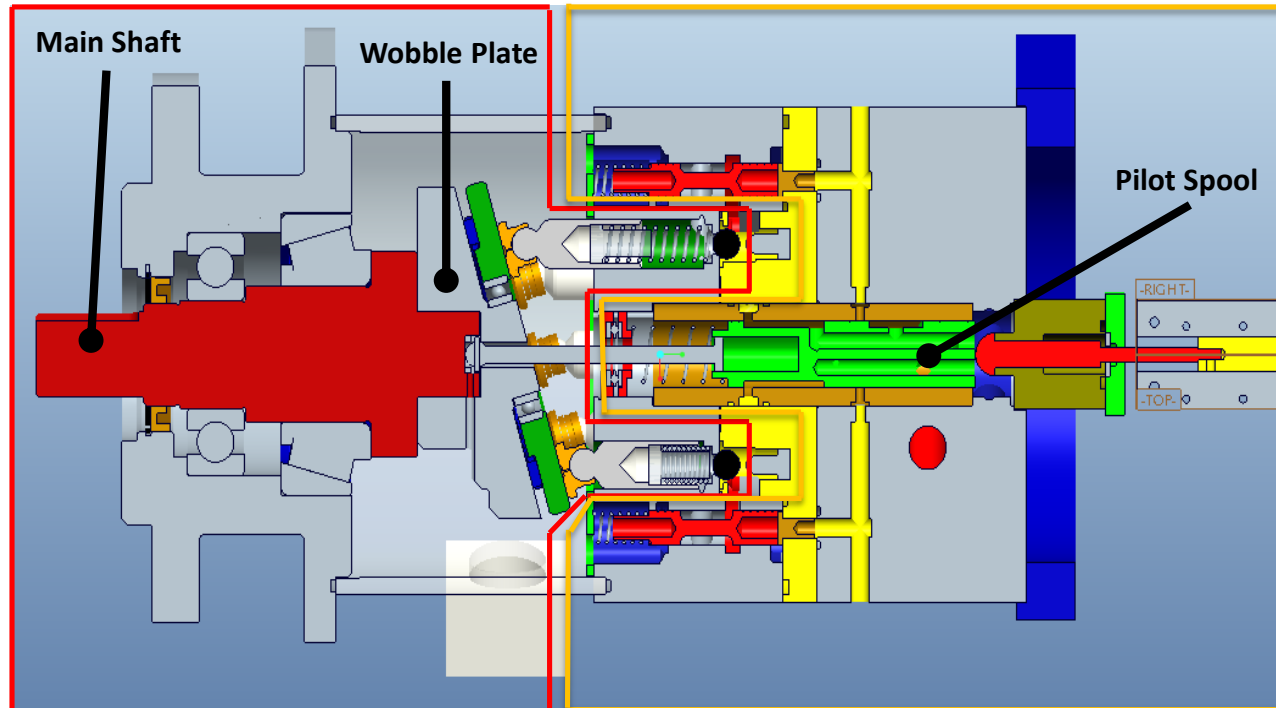


Results – pump efficiency at 13 MPa (2000 psi)





Cutaway CAD model

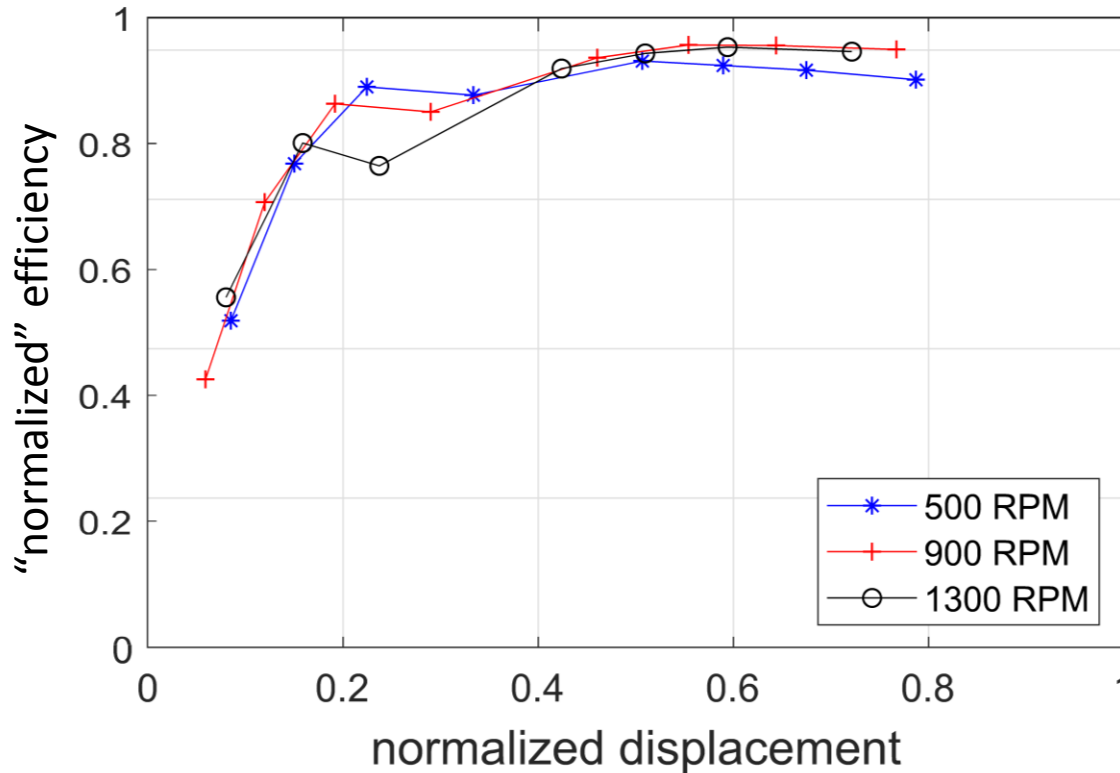


**Wobble Plate
Pump/Motor**

PSPP Controller

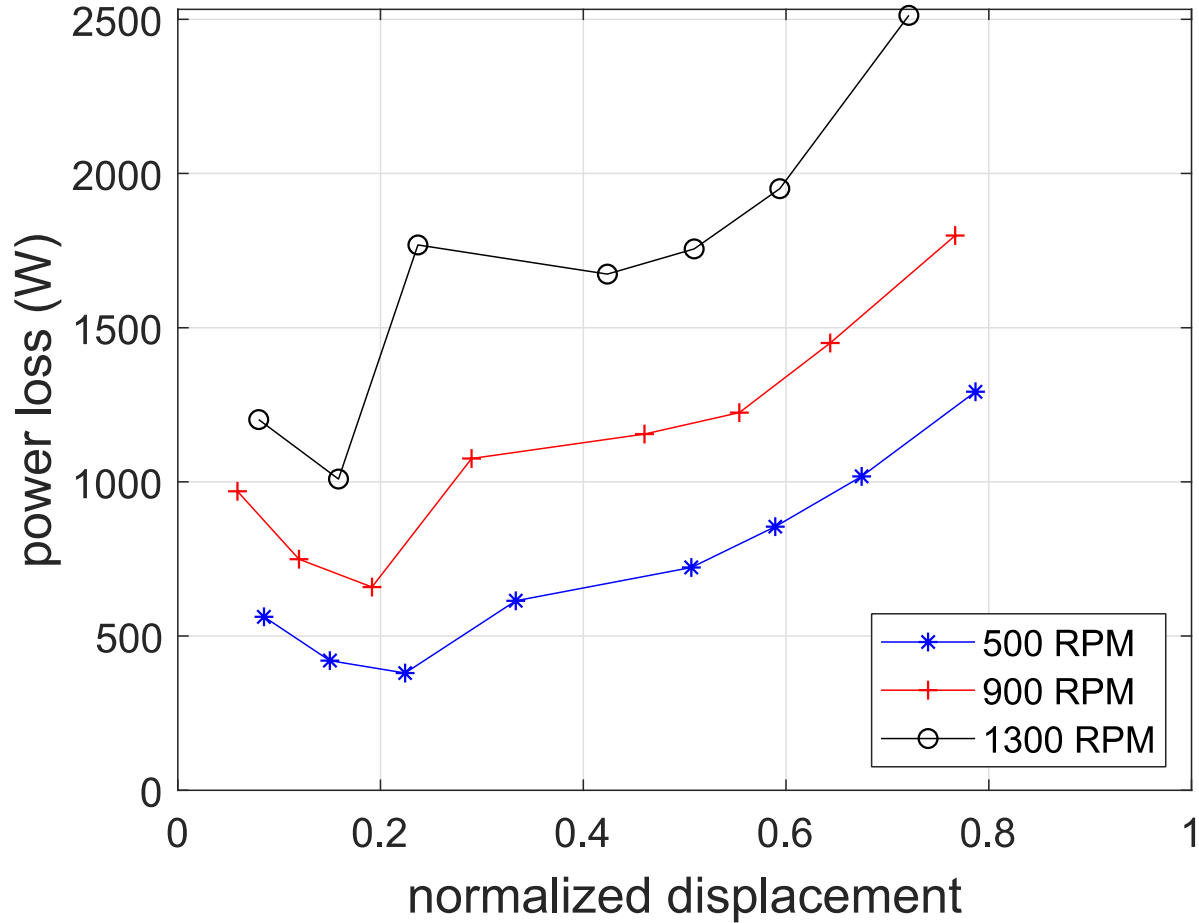


Results – PSPP “normalized” efficiency (remove effect of base wobble plate pump)



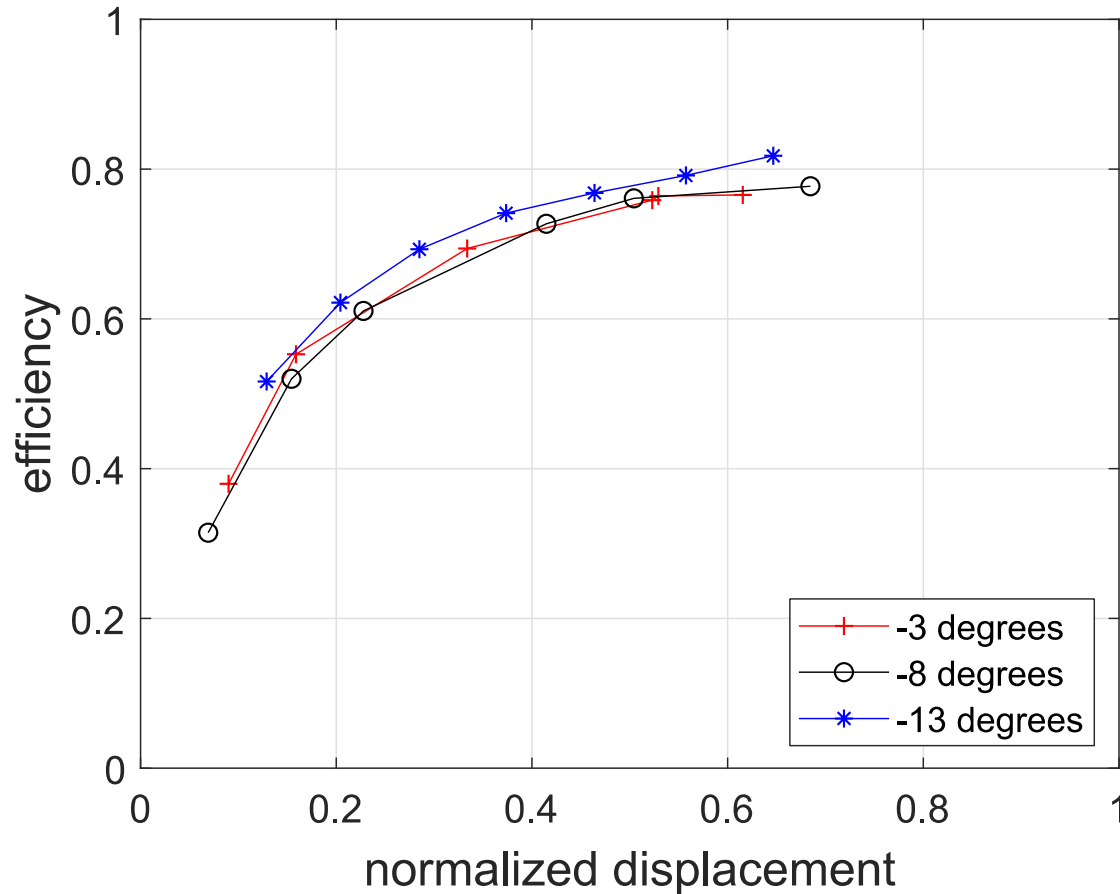


Results – power loss vs. displacement 13 MPa (2000 PSI)



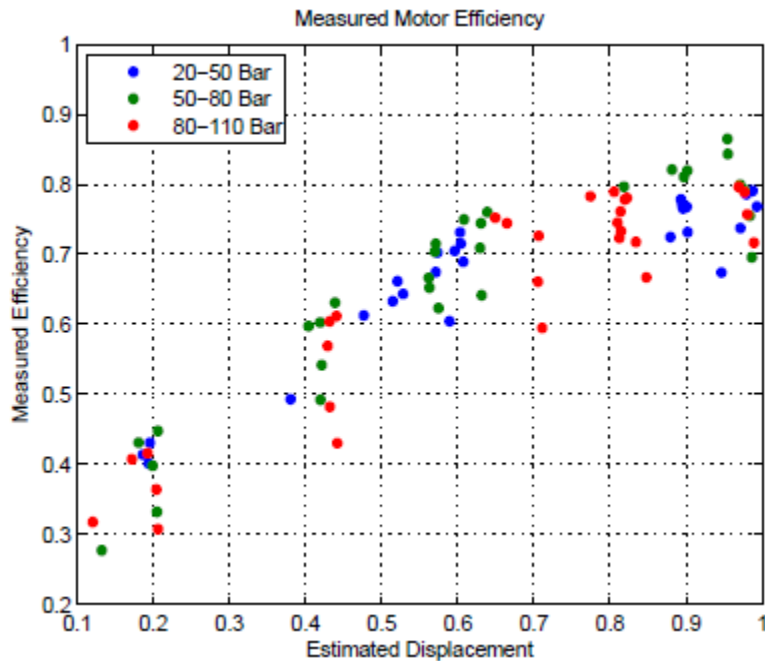


Results – offset angle effect at 900 RPM and 10 MPa (1500 PSI)

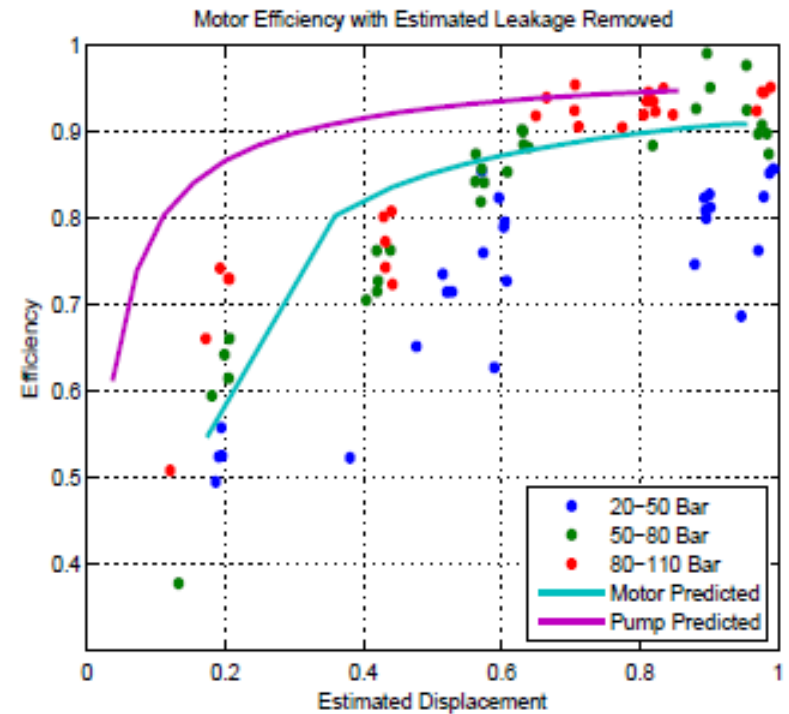




Previously measured motor efficiency



Measured



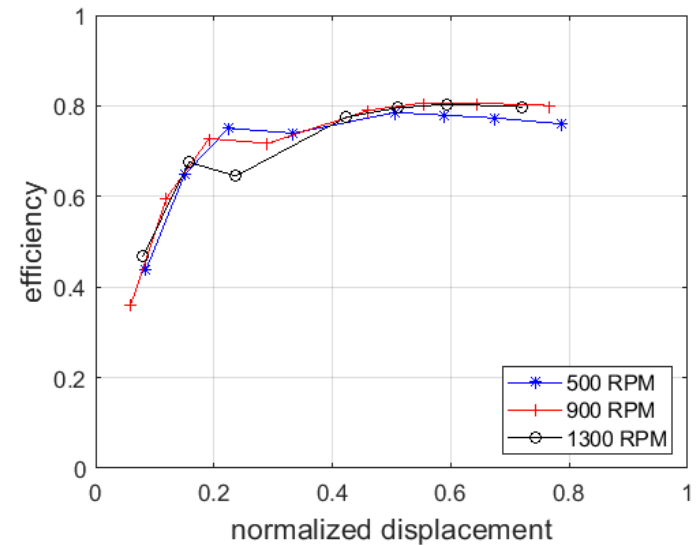
Estimated Leakage Removed

Tested with small mainstage valves, and no angle optimization



Next steps

- Test the prototype as a motor
- Design and build second generation prototype





Conclusions

- Controlled with hydromechanical valving
- Simple and rugged design
- No electronics required
- Good efficiency with PSPP



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