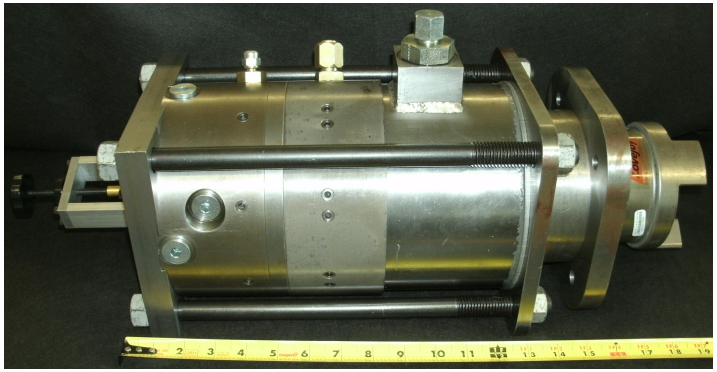
CENTER FOR COMPACT AND EFFICIENT FLUID POWER
A National Science Foundation Engineering Research Center

High Efficiency Hydraulic Pump-Motors Employing Partial Stroke Piston Pressurization



Alissa Montzka
Dr. Thomas Chase
Dr. Perry Li

Hydraulic power - applications

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

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

Existing Technology

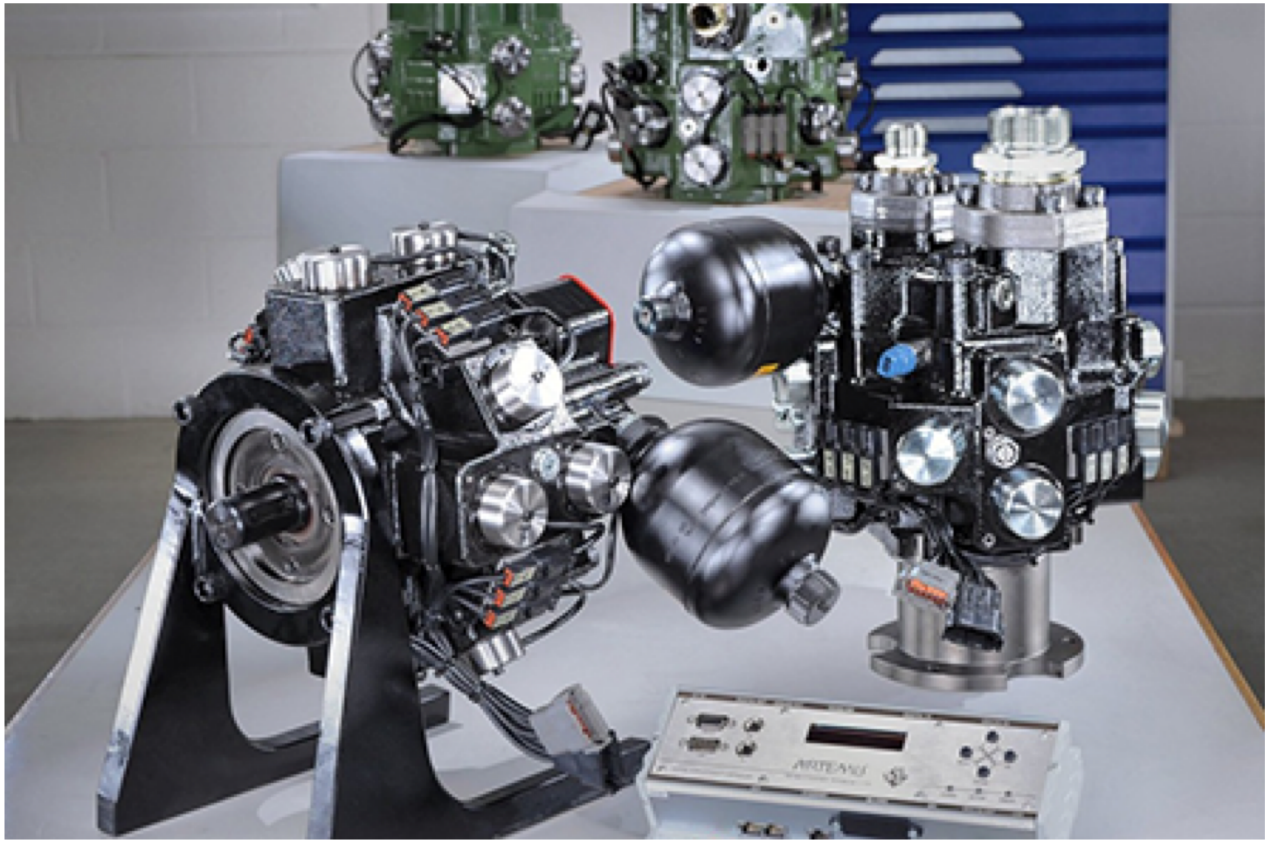


Image taken from: http://www.artemisip.com/our-products/industrial-hydraulic-pump

Artemis Digital Displacement

- Two valves per piston
- Electronic sensors and controls
- Expensive

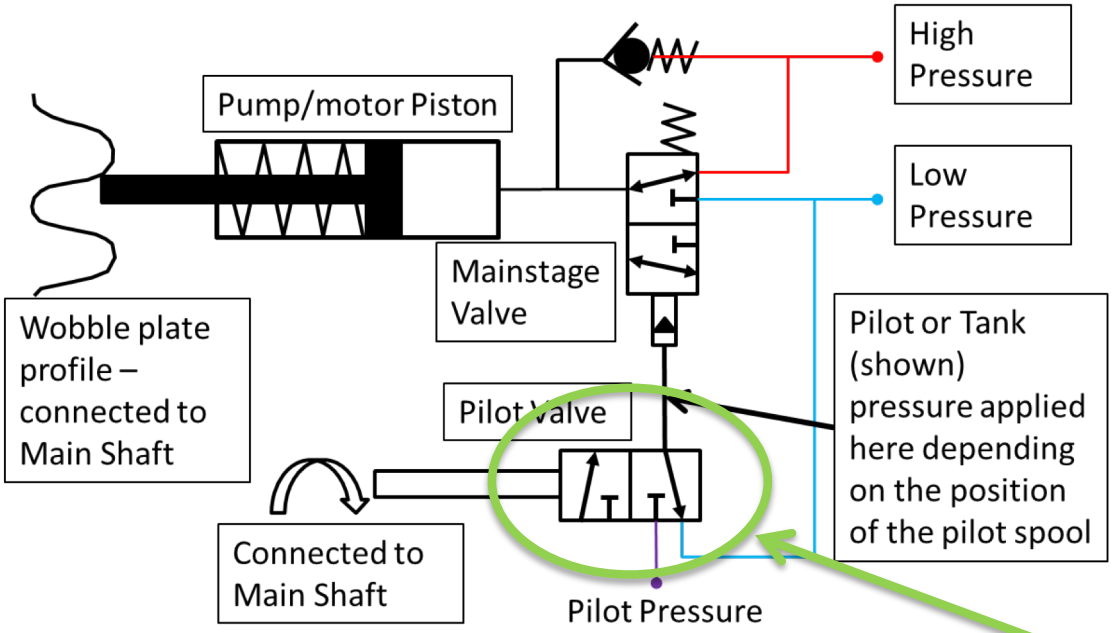
Our approach: Hydro-Mechanical Control

- Most discrete-piston implementations use electromagnetic valves:
  - 2 valves per piston
  - Artemis; others

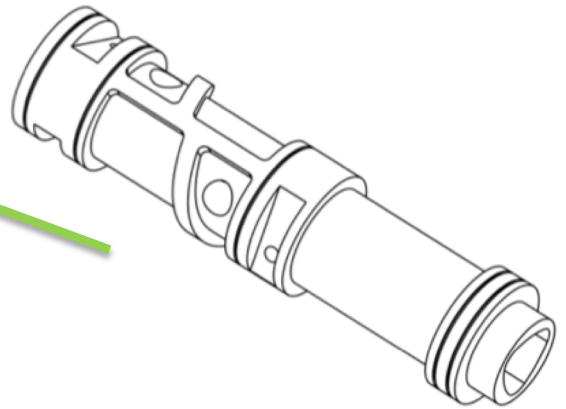
Advantages of mechanical control – valve timing connected to shaft

- **Robust**: No solenoids/wires/power electronics to fail on each piston
- **Cost:** No controllers for each piston
- **Simple**: only 1 control input needed
- **Mechanical and hydraulic power:** No need for electrical supply
- **Fast and repeatable timing:** speed scales up with pump speed

Concept



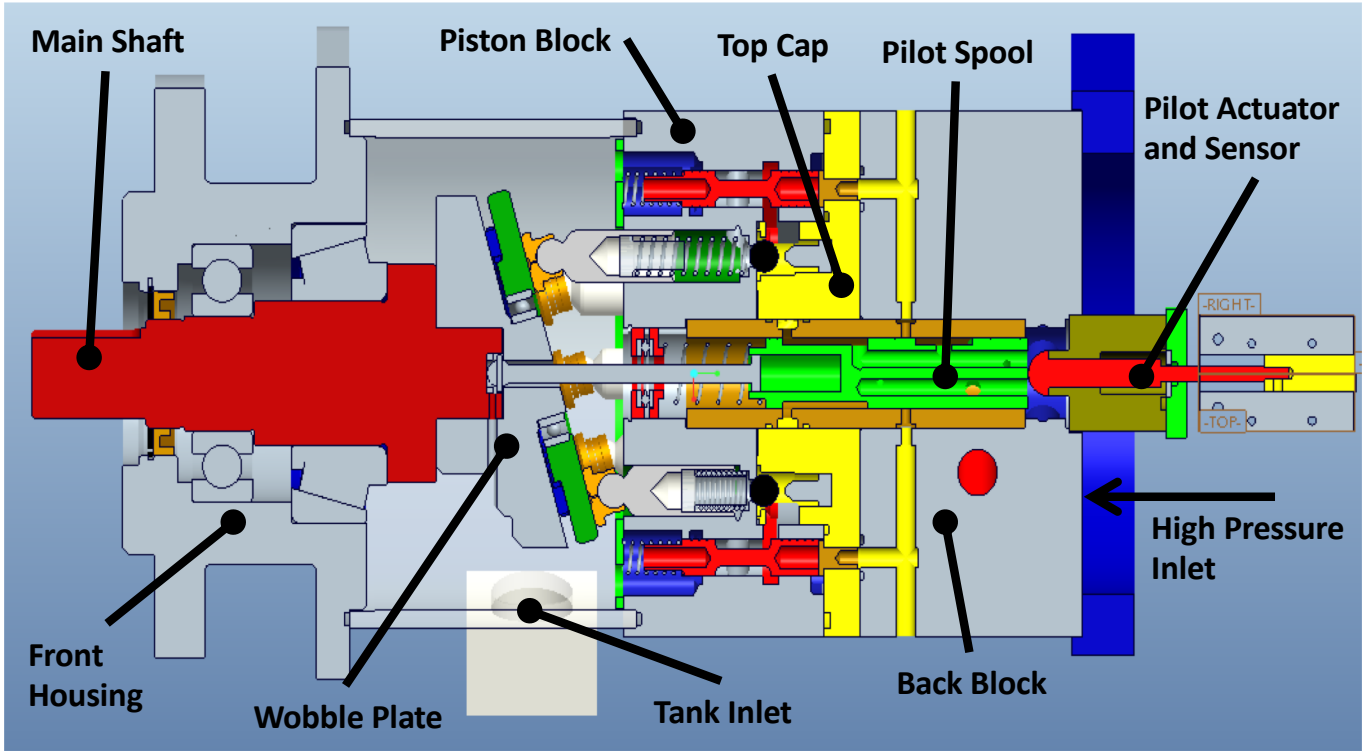
- Two stage
  - 2D Rotary valve pilot stage
  - Spool valve main stage



Pilot stage = 2 Degree-of-freedom valve:

- Rotation with shaft
- Translation: adjust displacement

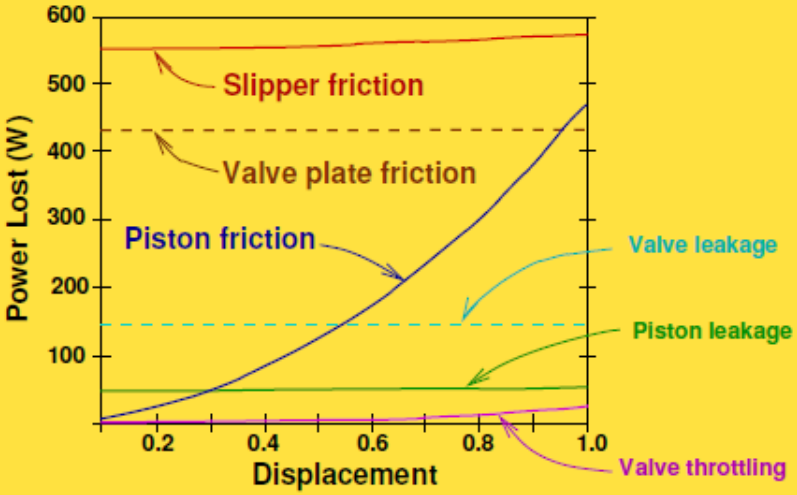
Cutaway CAD model



Why Is PSPP More Efficient?

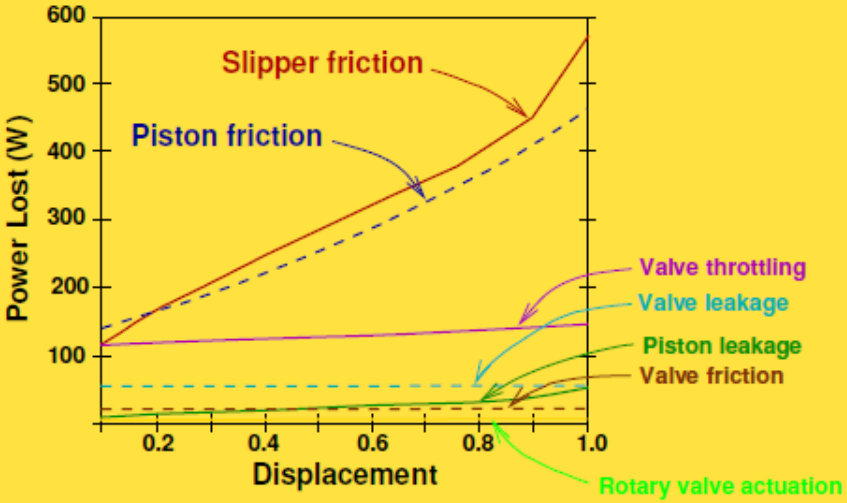
Simulated losses in 48 cc pumps operating at 200 bar and 1800 RPM:

Swashplate pump



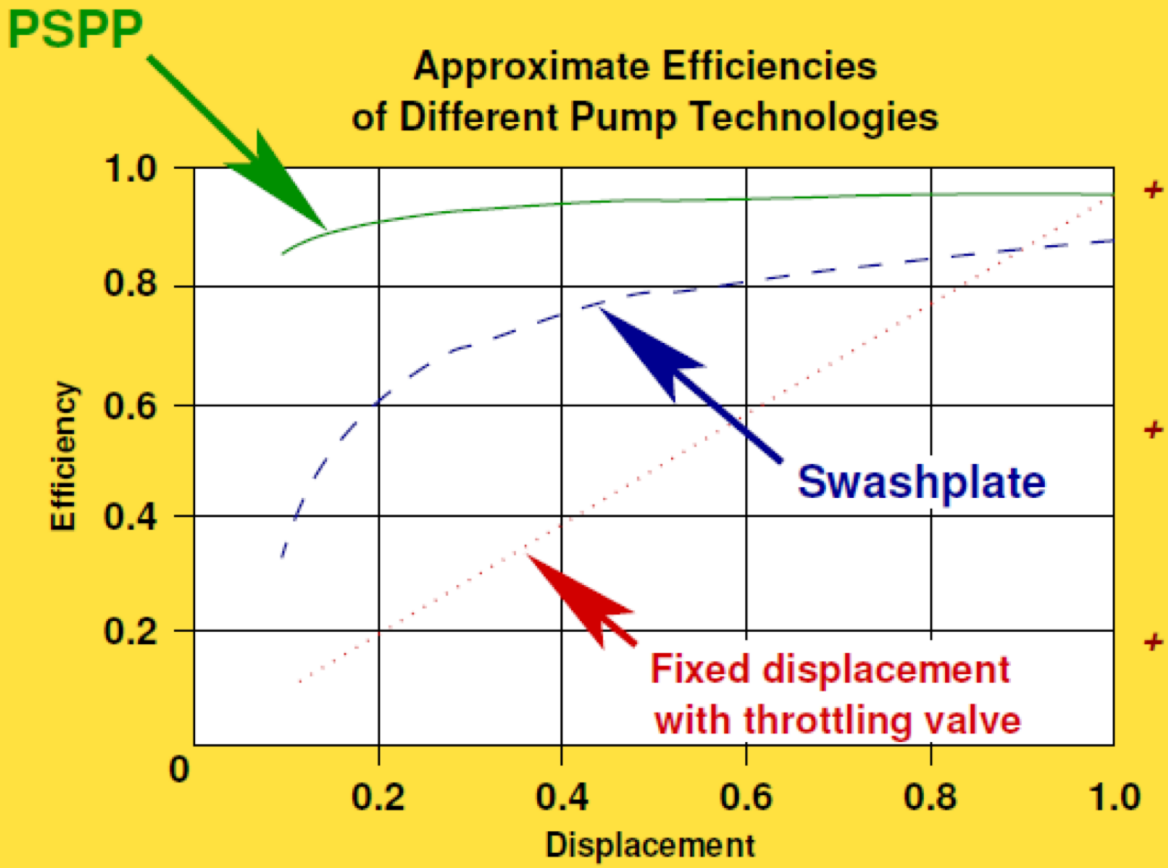
The two highest losses are slipper and valve plate friction

PSPP pump



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

Technical Payoffs:



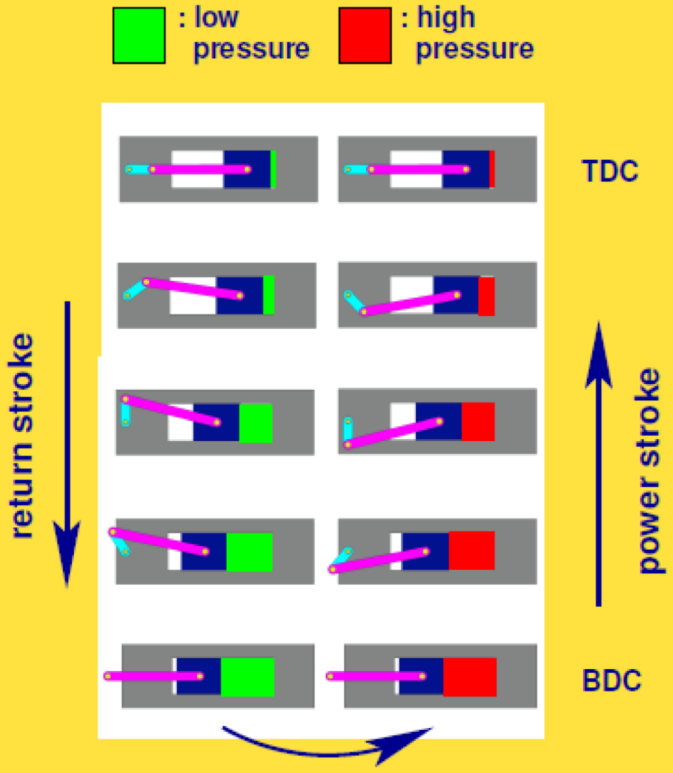
+ Saves energy!
(Fluid power accounts for ~3% of all domestic energy usage)

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

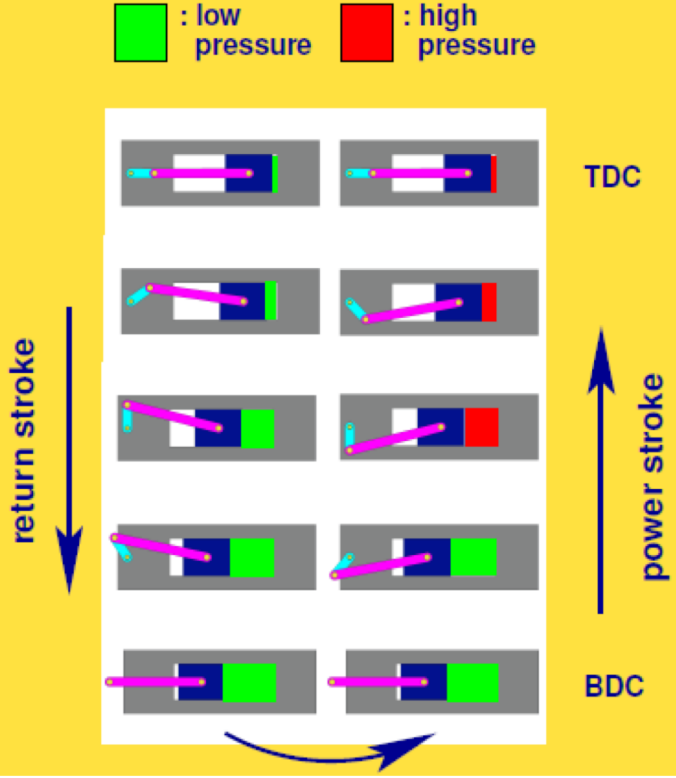
+ Other system components (especially cooling system) can be downsized

What is Partial Stroke Piston Pressurization (PSPP)?

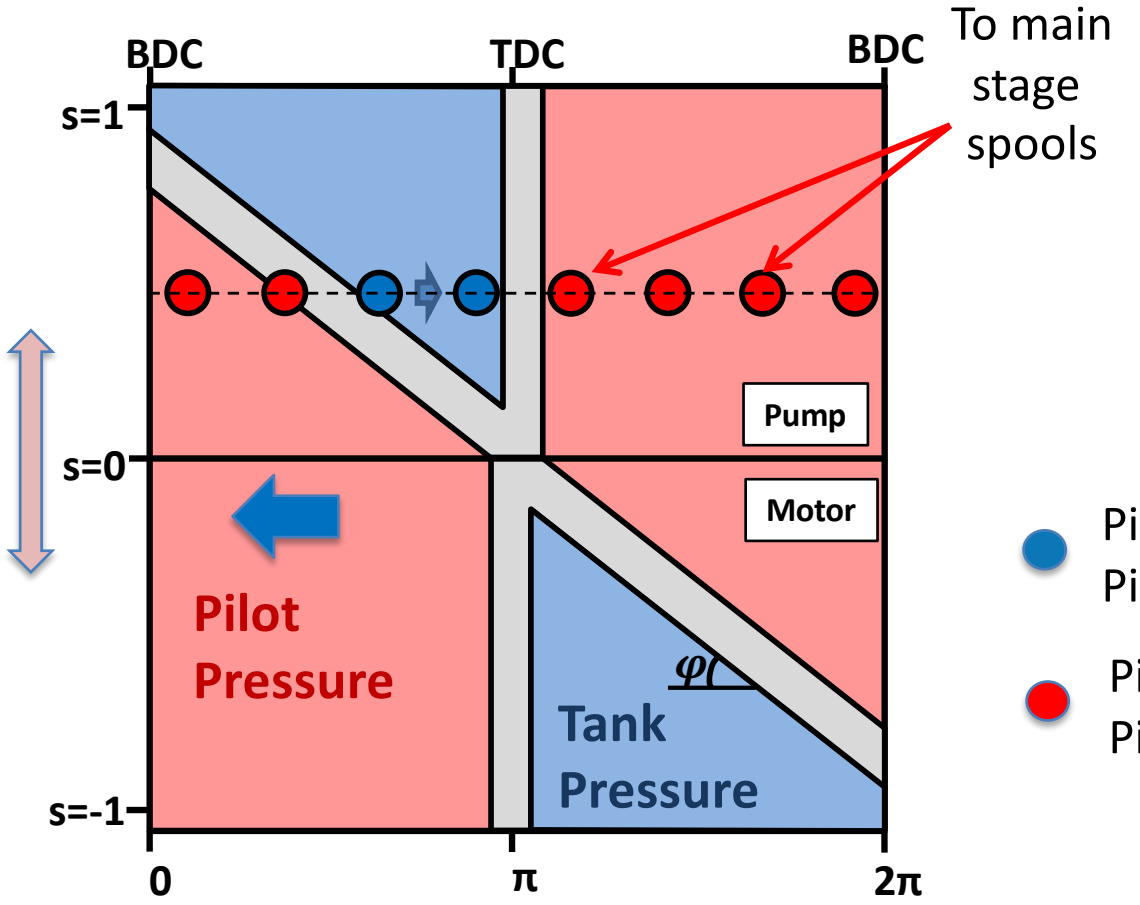
Variable Displacement Swashplate:
Piston is subjected to high pressure for the entire power stroke

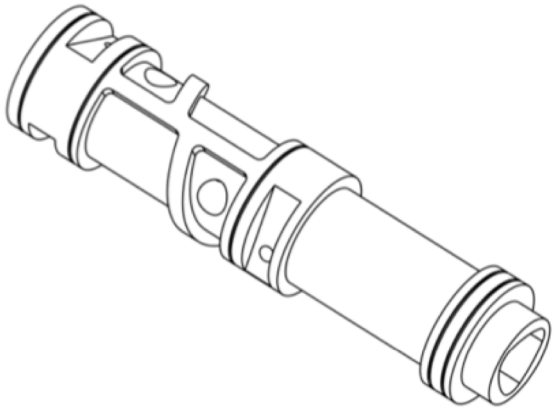


PSPP:
Piston is subjected to high pressure for only a fraction of the power stroke



Pilot Spool Profile



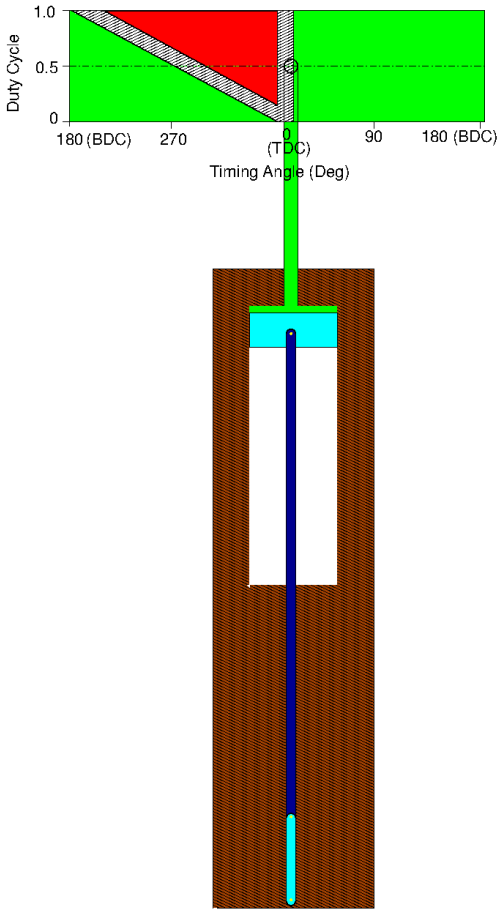


Pilot = Ptank,
Piston enabled (to high P)

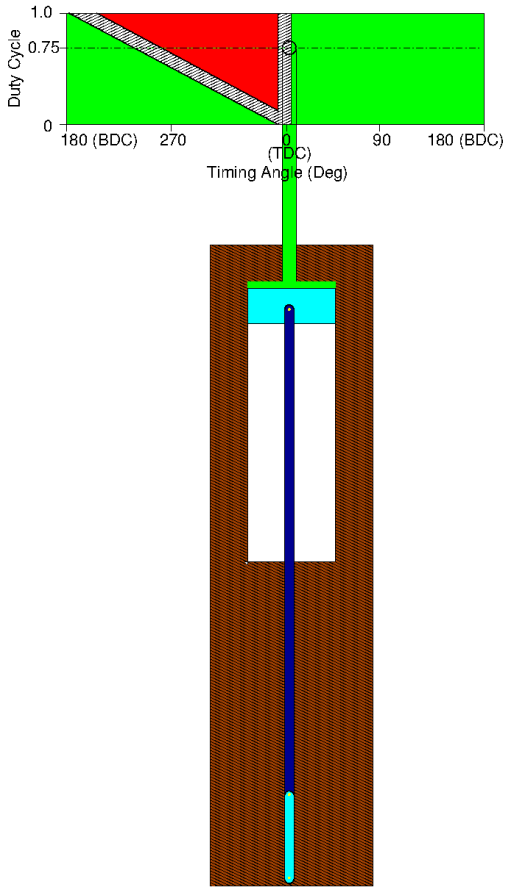
Pilot = Ppilot,
Piston disabled (to tank)

- Spool translation: changes stroke
  - Pump starts stroke late and motor ends stroke early
    - Ideal for reducing compressibility loss

Animation



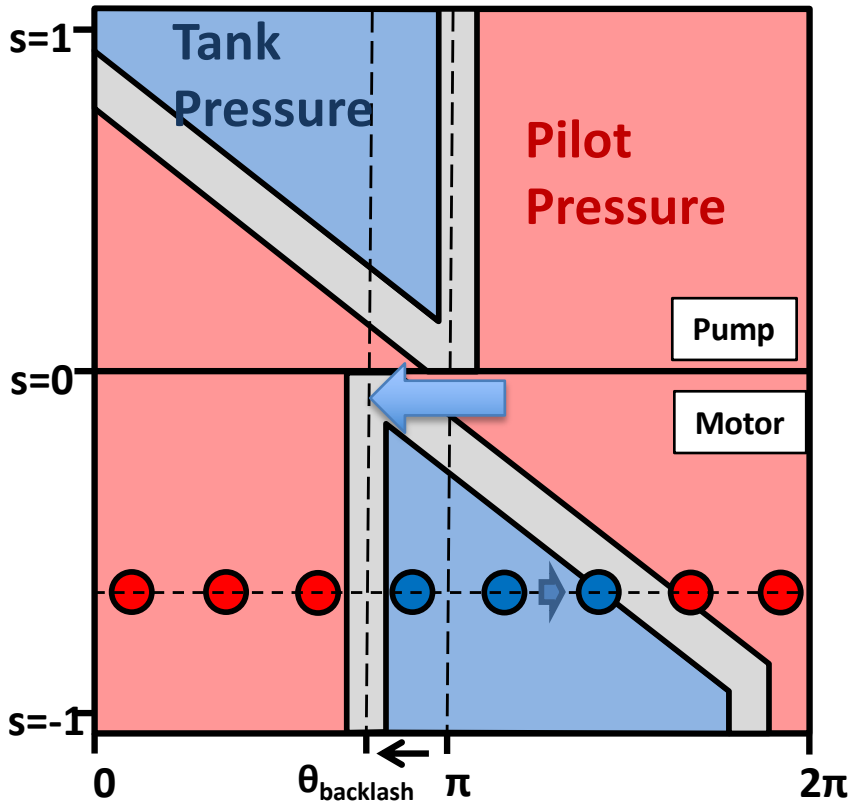
S = 0.5



S = 0.75

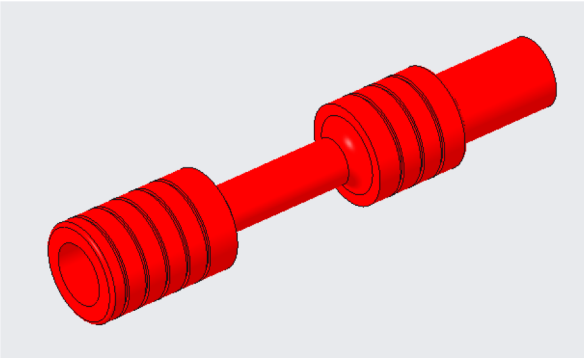
Pre-compression backlash

- 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

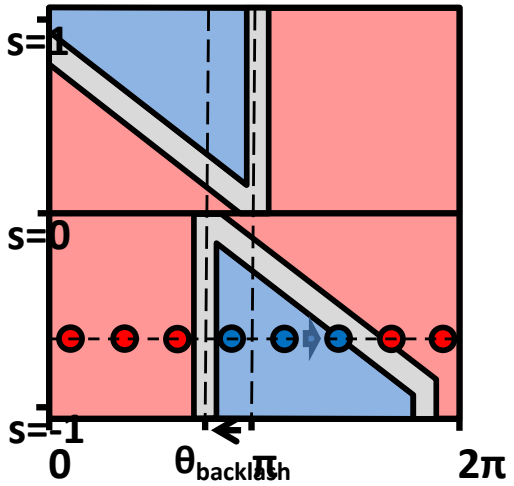


Improvements

- Radial clearance on mainstage valves has been reduced from ~40 microns to ~4 microns



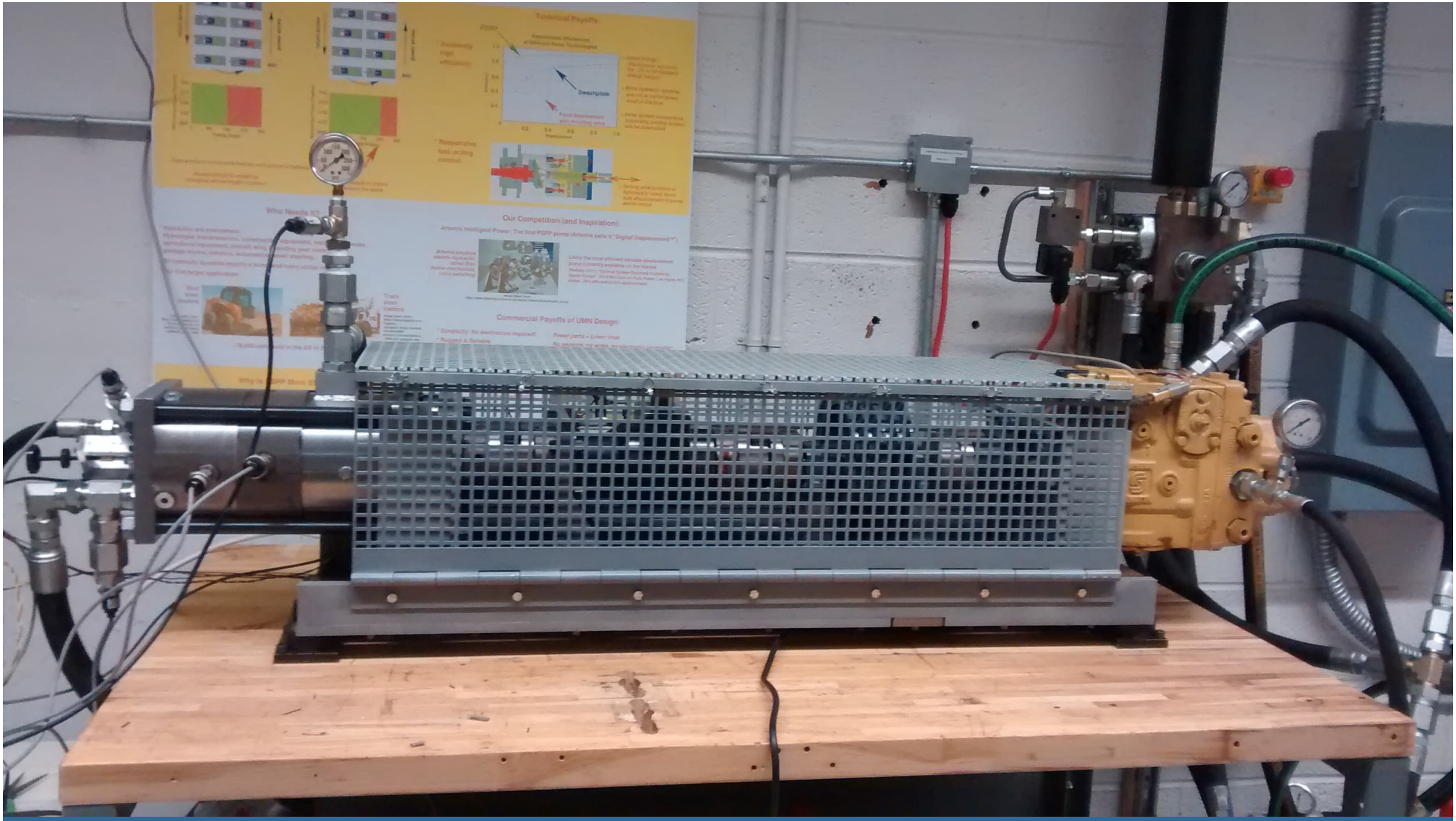
- Backlash angle setting now accessible from outside of pump case
- New mechanism for manually setting duty cycle of rotary spool



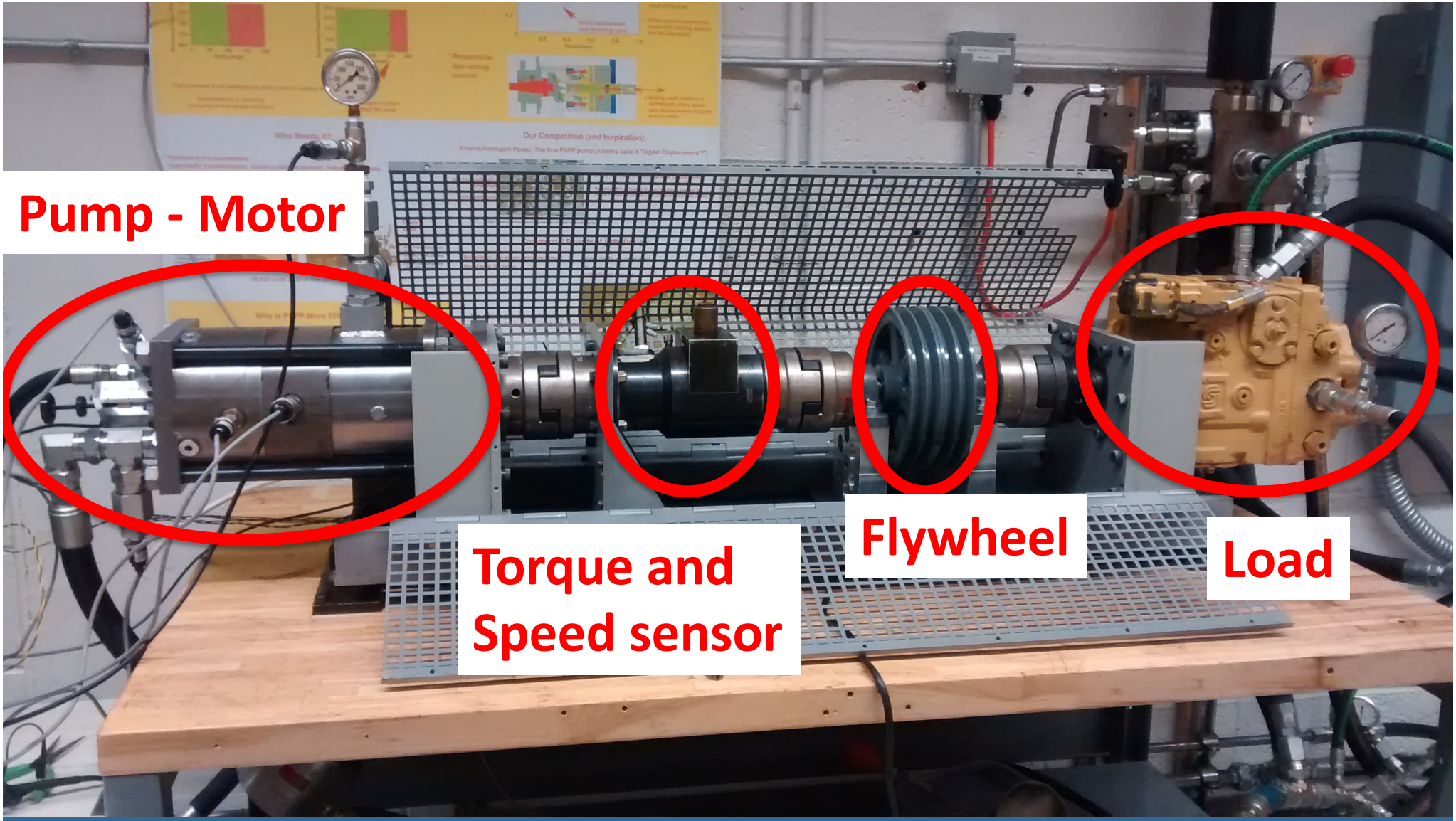
Improvements

- Rebuilt test stand and data acquisition system
- Able to see pumping when run at 1000psi

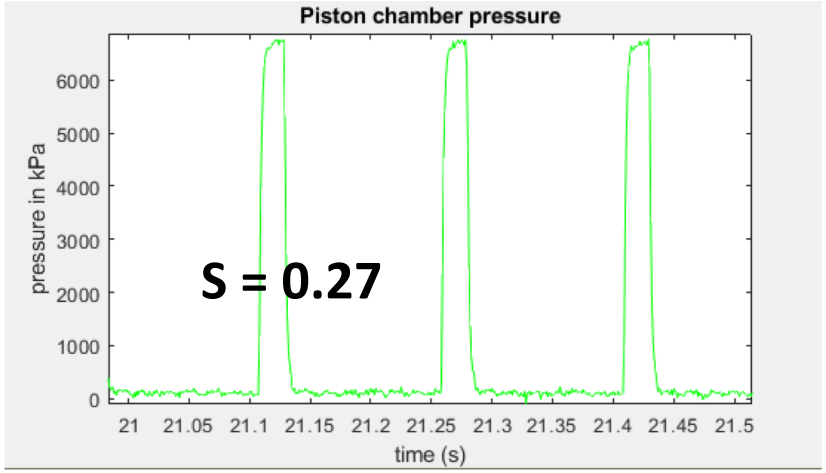
Test Stand

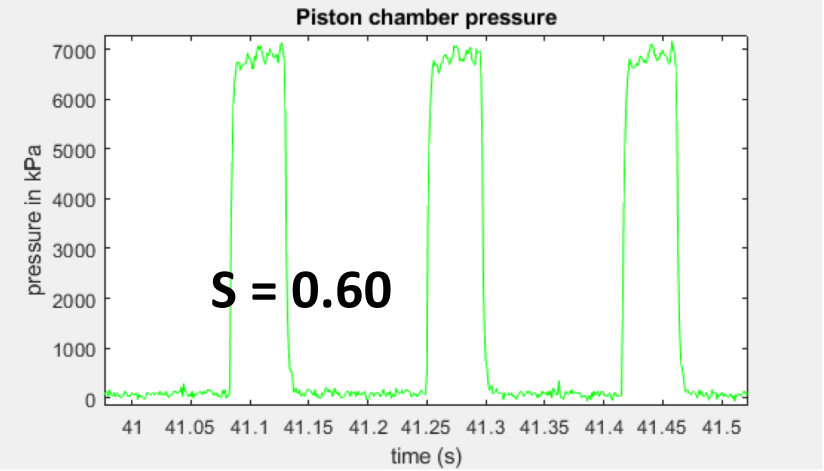

Theoretical Payoffs
Swashplate
Our Competition (and Inspiration):
Commercial Payoffs of UMN Design:

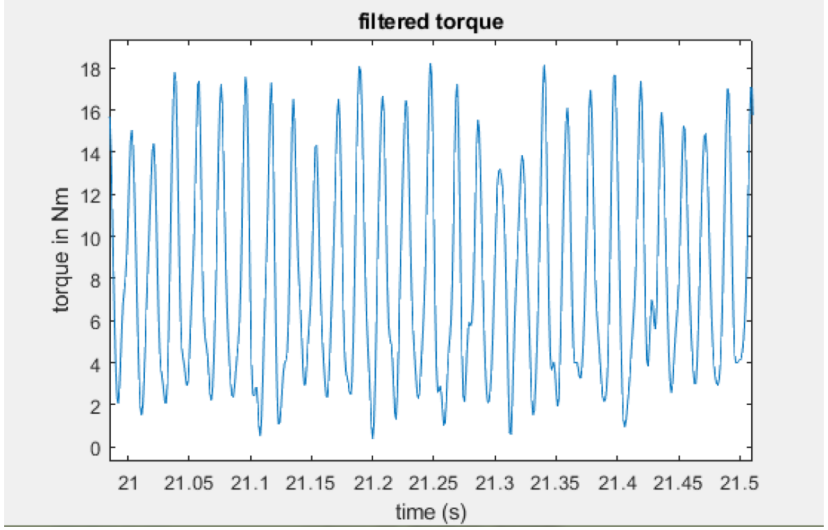
Test Stand

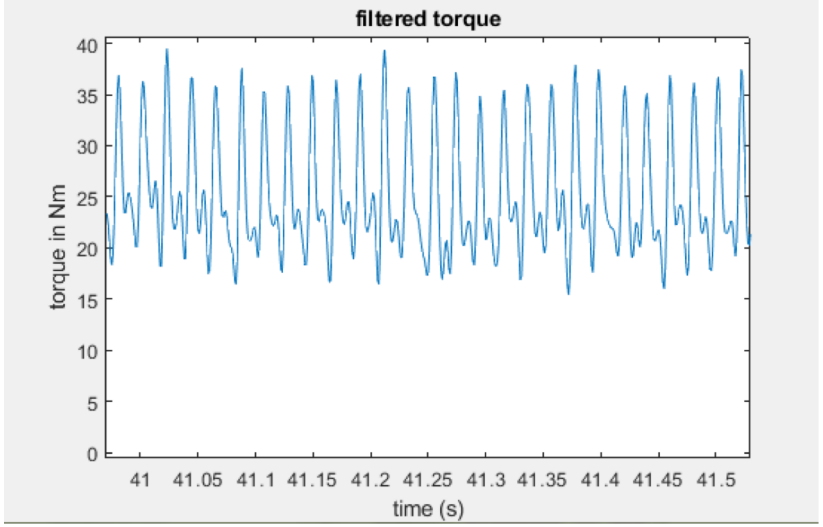


Results – pump efficiency data









Results – pump efficiency data

S = 0.27, measured efficiency = 6%

S = 0.60, measured efficiency = 10%

Potential reasons for low efficiency

- Pilot line leakage (mainstage valves could be moving too slowly causing throttling losses)
- Backlash timing set incorrectly
- Could be run at higher pressure

Conclusions

- Discrete piston control using mechanical valving has advantages of simplicity and ruggedness
- Our design uses:
  - Rotary pilot, 3-way spool main stage, partial stroke
- Measured efficiency is low, but should be improved by removing pilot leakage and setting timing angle