High Efficiency Hydraulic Pump-Motors Employing Partial Stroke Piston Pressurization

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Hydraulic power - applications
Existing Technology - Artemis Digital Displacement™

- 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
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
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

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TDC

return stroke

power stroke

BDC
Pilot Spool Profile

To main stage spools

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

- Spool translation changes stroke (displacement)
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

PSPP pump

The two highest losses are slipper and valve plate friction

* The valve plate is eliminated
* Slipper friction scales with displacement
Technical Payoffs:

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
Hydraulic Schematic of Test Stand

- **P**: Pressure sensor
- **Relief valve**: Indicates a relief valve
- **Speed sensor**: Indicates a speed sensor
- **Torque sensor**: Indicates a torque sensor
- **Flow meter**: Indicates a flow meter

Diagram shows the connections between different components of the test stand, including a test pump, drive motor, power unit, and various pressure and flow sensors.
Test Stand

- Pump - Motor
- Flywheel
- Motor - Load
- Torque and Speed sensor
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)

\[
eff = \frac{PQ}{T\omega}
\]
Cutaway CAD model

- Main Shaft
- Wobble Plate
- Pilot Spool
- 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

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