Four-Quadrant Multi-Fluid Pump/Motor

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Overview

- What is a four-quadrant multi-fluid pump/motor?
- Operating strategies
- Digital displacement control benefits
- Mechanically actuated prototype
- Model validation
- What are the next steps to develop an improved solution?
Background

Digital Four Quadrant Multi-fluid Pump/Motor

• Digital: utilizes digital displacement control
  – On/off valves at inlet and outlet of each piston

• Four-quadrant: capable of pumping and motoring each in CW and CCW rotation

• Multi-fluid: pump lubrication does not depend on operating fluid
Operating Strategies

◦ **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
Operating Strategies

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Benefits of Digital Displacement

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
Mechanically Actuated Valves

• First prototype use electrical actuation of on/off valves
• Mechanical actuation advantages
  – Fast and consistent
  – No electrical energy needed
  – No sensors or embedded controls
  – Actuation repeatability is increased
    • Critical for efficiency
Implementation

Inline MAV valve block and actuation mechanism
Prototype
Experimental Test Stand

Multi-piston digital pump/motor test stand

- 3-piston digital pump
- One on/off valves per piston
- One check valve per piston
- Three 2,000 Hz pressure transducers
- Two accumulators
Experimental Testing
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%
GT Suite Overview

• 1D multi-physics system simulation software

• GT-Suite Tools
  – CAD modeling and preparation
  – Converting 3D CAD model into GT model
  – Model building and run control
  – Post processing

• Hydraulics applications
  – System and component level models
  – Existing piston pump and valve component templates
  – Accurate pressure wave dynamics
  – Advanced features such as DoE and optimization
MAV Inline Schematic
CAD Model Preparation

Solid block

Flow volumes selected

Flow volumes extracted
Converting to GT Components

Split into individual parts

Converted into pipes and flow-splits
Model Geometry

GT-ISE components
MAV Inline Simulation
One Piston Simulation
One Piston Simulation

Piston crank-slider input
- Angle and speed defined by main driver
- Piston stroke angle profile
One Piston Simulation

Valve cam input
- Angle and speed defined by main driver
- Offset between each piston
- Valve stroke profile
One Piston Simulation

Check valve
- Flapper disk dimensions
- Spring properties
One Piston Simulation

On/off valve
- Valve opening area
- Poppet parameters
One Piston Simulation

End Environment

- Constant pressure
- Initial temperature and fluid conditions
- Represent constant pressure of accumulator
MAV Inline Simulation

103 bar, 500 rpm, 100% displacement

103 bar, 500 rpm, 25% displacement
Inline Simulation Results

Efficiency plots for 1500psi, 500 rpm
- Top Left - Volumetric Efficiency
- Top Right - Mechanical Efficiency
- Bottom - Total Efficiency
Next Generation MAV

• Optimal design, open-ended best system

• Requirements
  – One cam assembly for all pistons
  – Minimal gearing
  – Smaller physical size
  – Four quadrant capability
Radial Piston Orientation

Benefits

• Access to valves
• Thru-shaft
• Modular and compact design
• Fewer moving parts
Summary and Future Work

• Tested inline unit on existing digital pump/motor test stand
  – Results provided proof of concept for mechanical actuation

• Modeled and simulated inline unit
  – Validated modeling techniques

• Next steps
  – Model and simulate radial unit
  – Use simulation to determine optimal pump parameters
Contact Information

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