ME 4232: FLUID POWER CONTROLS LAB

Class #4
Hydraulic Fluid Properties
Notes

• Lab 2 Regrades
• Regrading Policy
• Undergraduate Research Position: Compressed Air Energy Storage Testbed
• Upcoming Labs:
  – Lab 7: Bleed Off Circuit
  – Lab 8: Check Valves: Direct & Pilot Operated
Agenda

• Feedback: Interesting / Challenging
• Check Valves
• Roles of Hydraulic Fluid
• Fluid Properties
  – Viscosity
    • Viscous Friction
    • Leakage
  – Bulk Modulus
  – Inertia
Feedback

Interesting
• Ingenious Component Designs
• Freedom in Lab = Learning
• Understandable Labs
• Practical Applications
• Power of Hydraulics
• Variety of Configurations
• Matlab for Data Analysis
• In Class Activities
• Analogies to Electrical

Confusing/Challenging
• Learning Matlab
• Circuit Diagrams
• Understanding Circuit Operation
• Frequency of Labs & Reports
• Lab Handout Wording
• Cavitation
• TA Language Challenges
• Want Lecture Schedule
Check Valves

• Allows flow only one direction
• Main uses are:
  – by-pass components
  – cylinder locking
Pilot Operated (open) Check Valve

- Allows reverse flow when pilot pressure is turned on
- Enables cylinder locking
- Consider force balance to calculate what pressures needed to open the check
Cartridge Valves

• Assemble Components into Circuits in a Manifold
  – Manifold = metal block with internal passages
Cartridge Valves (screw in)

- Check Valve

- Pilot Operated Check Valve
Cartridge Valve (Screw In)

• Relief Valve

• Pilot Operated Relief Valve
Roles of Hydraulic Fluid

• Primary:
  – Transmit Power

• Secondary:
  – Lubrication
  – Sealing
  – Heat Transfer / Cooling
Hydraulic Fluid Properties

Properties

- Viscosity
- Bulk Modulus
- Density
- Heat Capacity
- Vapor Pressure

Effect

- Dissipation (damping)
- Compressibility (spring)
- Inertia (mass)
- Thermal Inertia
Viscosity Index
Pipe Resistance
Friction Factor – Moody Diagram

Moody Diagram

Friction Factor

Material | \( \varepsilon \) (mm)
---|---
Concrete, coarse | 0.25
Concrete, new smooth | 0.025
Drawn tubing | 0.0025
Glass, Plastic, Perspex | 0.0025
Iron, cast | 0.15
Sewers, old | 3.0
Steel, mortar lined | 0.1
Steel, rusted | 0.5
Steel, structural or forged | 0.025
Water mains, old | 1.0

Friction Factor = \( \frac{2d}{\rho V^2 l} \Delta P \)

Reynolds Number, \( Re = \frac{\rho V d}{\mu} \)

Transition Region

Laminar Flow

\( \frac{64}{Re} \)

Complete turbulence

Smooth Pipe

Relative Pipe Roughness \( \varepsilon \)
Example: 3 MW Wind Turbine, 35 MPa

Hydraulic Fluid: ISO 46
- $\nu = 46$ cSt
- $\rho = 870$ kg/m$^3$

Pipe: 100 m long, 20 cm diameter, perfectly smooth

Find:
1. Determine the flow rate and average fluid velocity.
2. Calculate the Reynolds number. Laminar or Turbulent?
3. Find the friction factor.
4. Calculate the viscous pressure drop.
5. How does this compare to the pressure difference due to gravity?
Hydraulic Connectors
Example

Fluid Properties:
\( \rho = 870 \text{ kg/m}^3 \)
\( \nu = 46 \times 10^{-6} \text{ m}^2/\text{s} \)

Q1: Assuming the leakage past the spool is small, find the pressure \( P \)

Q2: How long does \( L \) need to be for the leakage to be < 0.01% of the pump flow?
Efficiency vs Viscosity vs Temperature

- For hydraulic components (e.g. pumps, motors, actuators) with moving parts, there is always a trade-off between
  - Volumetric efficiency [leakage]
  - Mechanical Efficiency [friction]
  - Total efficiencies for pumps and motor given by:

\[ \eta_{total} = \eta_{vol} \cdot \eta_{mech} \]

- Optimal viscosity exists for a given component (and system)

However, viscosity changes dramatically by temperature!
Bulk Modulus
Research Topic: Fluid Compressibility in Digital Hydraulics

• Major Form of Energy Loss
• Widely Varying Bulk Modulus Models

Goal: Understand the Role of Fluid Compressibility on the Performance and Efficiency of Switch-Mode Circuits
Bulk Modulus Models

Bulk Modulus: $\beta = -V \frac{dP}{dV}$

- Many Models Available in Literature

**Basic: Akers et al.**

$$\beta_e = \frac{V_T}{V_T - V_a} \frac{1}{1 + \frac{V_a}{\beta V_T}} \approx \frac{1}{1 + \frac{V_a}{\beta_V}}$$

**Merritt**

$$\beta_e = \beta \left( \frac{P\gamma}{R\beta + P\gamma} \right)$$

**Hayward**

$$\beta_e = \beta \left( \frac{\left( \frac{P}{P_o} \right)^\gamma + R}{\frac{R\beta}{\gamma P} + \left( \frac{P}{P_o} \right)^\gamma} \right)$$

**Cho et al.**

$$\beta_e = \beta \left( \frac{P^{1+\frac{1}{\gamma}}}{P^{1+\frac{1}{\gamma}} + P_o^{\frac{1}{\gamma}} R \left[ 1 - c_1 (P - P_o) \right] \left( \frac{\beta}{\gamma} - P \right)} \right)$$
Experimental Validation

- Vary: Entrained Air, Pressure, $V_{\text{switched}}$
- Measure: Density, Bulk Modulus, Efficiency
Bulk Modulus Calculation

Based on Sonic Velocity: $\beta_e = \rho c^2 = \rho \left( \frac{L}{T} \right)^2$

- Cross-correlation of Pressure Waves