Selecting Proportional Valves and High Response Valves

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Bethlehem PA
So Many Proportional and Servo Valves

Which One Do I Need?
Considerations for a Basic Application

- Most Important Issues Are
  - Flow Requirement (Easy to Find)
    - Specified or Desired Actuator Speed
    - Limits by Pump flow, HP, Budget
  - Dynamic Performance
    - Acceleration
    - Cycle Time
    - Accuracy
    - Especially in Closed Loop Applications
Considerations for a Basic Application

- Control Valves Belong to 3 Categories
  - Proportional Valves
  - Servo Valves
  - Servo-Solenoid or High Response Valves
Proportional Valve without Feedback
4WRA - Direct Operated

- Proportional Valves have Proportional Spool in Cast Housing – No Sleeve/Spool
  - Good Flow Capacity
  - Low Cost
- Solenoid Current Is Directly Proportional To Spool Position

Example: 4WRAE6
data sheet RE29055
Proportional Valve without Feedback
4WRA - Direct Operated

- Each Size Directional Body Has Different Spool Flow Capacities
- Proportional “Nominal Flow” is measured at $\Delta p = 145$ psi (10 bar)
- Example: 4WRA (Size 6 & 10)
  Nominal Flows: 7 to 60 LPM @ $\Delta p$
  145 psi (10 bar)
- 145 psi Drop Across This Valve is Not Typical of Your System!
  - Leading to a Common Mistake: Super-sizing the Spool

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Estimate Pressure Drop Required Across Valve
(System Pressure - Load Pressure - Other Pressure Drops)

Find Target Flow At ~90% Command, Compare $\Delta p_{\text{curve}}$ with above

Avoid High Valve $\Delta p$ (Above 50% System Pressure Dropped in Valve Can Cause Rotational Forces on Proportional Spool)
Proportional Valve without Feedback
4WRA - Direct Operated

- Direct Operated Valves Have Power Limits, $Q_{\text{valve}} \cdot \Delta p_{\text{valve}}$
- Flow Forces Try to Center Spool

Power Limit
30 LPM 4WRA6
RE29055

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Proportional Valve without Feedback
4WRA - Direct Operated

- **Step Response**
  - 4WRA 6
  - RE 29055

- Hysteresis \(< 5\%\)  
  - Reversal Error \(< 1\%\)  
  - Response Sensitivity \(< 0.5\%\)
Proportional Valves without Feedback
4WRZ - Pilot Operated

- Larger Flow Proportional, like 4WRZ
  Nominal Flow ...1000 LPM (265 GPM)
  @ $\Delta p$ 10 bar (145 psi)
- Normally Open Loop Control,
  Accel/Decel set by Ramp Time
- Clamp, Transfer, Hydraulic Motor Speed

4WRZ  (external amplifier)
4WRZE  (internal electronics)
RE 29115

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Proportional Valves with LVDT Feedback
4WRE - Direct Operated

- Adding Spool Position Feedback Improves Performance
  - Much Lower Hysteresis ≤ 0.1%
  - Better Accuracy ≤ 0.05%
  - Greater Flow Capacity
    (4WRE: 4 to 75 Lpm @ 10 bar Δp)
Proportional Valve Spools

Spool Types

- **E-spool**: All Ports Blocked, Overlap
  - Differential Cylinder Can Drift
  - Spool Jump Compensation Reduces Deadband
  - Closed Loop Positioning Possible with Advanced PID-Controller

- **V-spool**: ±1% Underlap
  - For Closed Loop Position, Pressure, and Force Control

- **W-spool**: 3% Leakage A & B to T
  - For Cylinders, Not Good for Closed Loop

- **2:1 Spools for Diff. Cylinders can**
  - Prevent Cylinder Cavitation
  - Improve Decel/Reversal Time
  - Balance Valve $\Delta p$ in each path

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Proportional Valves with LVDT Feedback
4WRE - Direct Operated

- Valve Frequency Response (about 40 Hz small signal)
- Satisfies Many Closed Loop Application Requirements

Bode-diagram 4WRE6 V
RE 29061

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Servo Valves
4WS2EM (6, 10)

- Servo Valve Is Sleeve and Spool in Main Stage
- Servo Torque Motor and Orifices Control Pressure Balance to Position Main Spool
Servo Valves
4WSE3E (16, 25, 32)

- Flows to 1000 Lpm at 70 bar Δp
- Sleeve/Spool in Main Stage
- Longer life (HFC water glycol, or other difficult fluids)

4WSE3E
RE29620, RE29621, RE29622
High Response Valves
(Servo-Solenoid Valves)
Servo Solenoid Valves
4WRPEH - Direct Operated

- Very Fast Solenoid with LVDT Feedback
  - Directly Positions Spool
- No Flapper/Nozzle
- No Jet-pipes
- No Pilot Leakage

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Servo Solenoid Valves
4WRPEH - Direct Operated

- Spool and Sleeve Assembly
  - Zero Overlap
  - Accurate
  - Symmetrical
  - Linear
- Normal Filtration
- Main Sleeve: Nominal Flow
  - 2 to 100 Lpm (size 6 & 10)
  - @ Δp 70 bar or 1000 psi!
    like a Servo Valve

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4WRPH6, 4WRPEH6,
4WRPEH10
RE29035, RE29037
- Spool Options
  - All Zero Overlap, for Close Loop Applications
  - Failsafe Position (Power Off / Fault)
  - May Eliminate Need for Blocking Valve

C5, C1 have 2:1 flow ratios
Servo Solenoid Valves
4WRPEH - Direct Operated

- Most Reliable OBE Available
- 25g for 24 Hours in 3 Axis
- Long Service Life
- 60 to 100 Hz @ -90 Deg, small signal
- Outstanding Performance for Many Closed Loop Applications

4WRPH6, 4WRPEH6, 4WRPEH10
RE29035, RE29037
Servo Solenoid Valves
4WRL - Pilot Operated

- Pilot is 4WRPEH (Sleeve/Spool)
- Proportional Main Stage with LVDT Feedback
- Many Same Advantages
  - Robust
  - Reliable

4WRL
RE 29088
RE 29089

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Servo Solenoid Valves
4WRL - Pilot Operated

- Main Stage Proportional Spool in a Cast Housing
- Nominal Flow (Size 10 to 35)
  - 50 to 1100 LPM @ 10 bar or 145 psi ∆p, like a Proportional

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Servo Solenoid Valves
4WRLE - Pilot Operated

- V-Spool with Linear Flow Characteristic Can Improve System Performance
- Higher P-Gain in Controller Reduces Following Error
- Easier System Tuning

Standard Flow Curve
4WRLE 10 V55M

New Flow Curve
4WRLE 10 V55L

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Servo Solenoid Valves

- Protect each OBE with 2.5 Amp, Fast acting Fuse!
Valve Matrix and Project Worksheet (Hyvos)

Position-controlled actuators with proportional directional valve and external closed-loop control electronics

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### Matrix of proportional directional valves

<table>
<thead>
<tr>
<th>Valve model</th>
<th>Nominal flow (l/min)</th>
<th>Nominal Δp (bar)</th>
<th>Data sheet</th>
<th>Overshoot compensation (with E, W, gaug)</th>
<th>Typical application *</th>
<th>Open control loop</th>
<th>Closed-loop position control</th>
<th>Closed-loop pressure control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4WRA(E)</td>
<td>Size 6: 7, 15, 30</td>
<td>10</td>
<td>29055</td>
<td>Yes</td>
<td>Very Low</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size 10: 90, 60</td>
<td></td>
<td></td>
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<tr>
<td>4WRPE(E)</td>
<td>Size 6: 6, 18, 32</td>
<td>10</td>
<td>29025</td>
<td>Yes</td>
<td>Low</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size 10: 50, 80</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4WRE(E)</td>
<td>Size 6: 4, 8, 16, 32</td>
<td>10</td>
<td>29051</td>
<td>No</td>
<td>Medium</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Size 10: 25, 50, 75</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4WRSE</td>
<td>Size 6: 4, 10, 20, 35</td>
<td>10</td>
<td>29057</td>
<td>No</td>
<td>High</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Size 10: 25, 50, 80</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4WRPE(H)</td>
<td>Size 6: 2, 4, 12, 24, 40</td>
<td>70</td>
<td>29035</td>
<td>No</td>
<td>High</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Size 10: 50, 100</td>
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<td></td>
</tr>
<tr>
<td>4WRREH</td>
<td>Size 6: 4, 8, 12, 24, 40</td>
<td>70</td>
<td>29031</td>
<td>No</td>
<td>Very high</td>
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<td>✓</td>
<td>✓</td>
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<tr>
<td>4WS(E)x2E</td>
<td>Size 8: 2, 5, 10, 15, 20</td>
<td>70</td>
<td>29564</td>
<td>No</td>
<td>Very high</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Size 10: 20, 30, 45, 60, 75, 90</td>
<td>70</td>
<td>29563</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4WRZ(E)</td>
<td>Size 10: 25, 50, 85</td>
<td>10</td>
<td>29115</td>
<td>No</td>
<td>Very Low</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td></td>
<td>Size 16: 100, 160</td>
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<tr>
<td></td>
<td>Size 25: 220, 925</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Size 32: 350, 920</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size 32: 1000</td>
<td></td>
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</tbody>
</table>

- **Very Low <10 Hz, Low 30 Hz, Med 60 Hz, High 120, Very High 250 Hz**

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Hydraulic Response of Cylinder

- Closed Loop Hydraulic Response Could Be Tested
- This does not include the Control Valve
- \( f_h = \text{Number of Oscillations per Second} \)
- Oscillations Reduce Due to Damping

\[
f_h = \frac{1}{T}
\]
Position Control with Valve and Cylinder

- Closed Loop Performance Depends on Valve and Cylinder
  - Valve Frequency Response $f_v$ (from data sheet)
  - Hydraulic Natural Frequency $f_h$ (simplified as a mass-spring model)
    - $m$: Moving Mass
    - $C$: Spring Constant of Fluid under Compression
      (fluid on each side of the piston acts like a spring)

\[
f_h = \frac{\sqrt{\frac{C}{m}}}{2\pi}
\]

\[
f_o = \frac{f_v f_h}{f_v + f_h}
\]

Hydraulic Natural Frequency

Valve Frequency

Hydraulic Mass-Spring Model

Plus Valve Response

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Closed Loop Analysis of Cylinder

- Spring Constant (Hooke’s Law)
  \[ C = \frac{\Delta x}{F_x} \]
  Displacement of Spring
  Force acting on Spring

\[ \Delta x = \frac{\Delta V}{A} \]
\[ F_x = p A \]

\[ p = \frac{\Delta V E}{V_o} \]

\[ f_h = \sqrt{\frac{E A^2}{V_o m}} \]
\[ 2\pi \]

- Calculations Can Get Complicated
- Results are Only Approximate

\[ \Delta V = \text{Volume change in cylinder } A \]
\[ E = \text{Area of cylinder (each side)} \]
\[ V_o = \text{Volume of trapped fluid} \]
\[ m = \text{Effective mass} \]
\[ 2\pi \text{ radian/sec} = 1 \text{ Hz} \]
Axis Worksheet

- Define Application
- Cylinder Parameters
- Piping Parameters
- Supply Pressure
- Opposing Forces
- Command Profile

<table>
<thead>
<tr>
<th>Cylinder Parameters</th>
<th>Value</th>
<th>Unit</th>
<th>Comment (min, max, range, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore d</td>
<td></td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Piston rod A</td>
<td></td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Piston rod B</td>
<td></td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Stroke s</td>
<td></td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>Internal bore of piston</td>
<td></td>
<td>mm</td>
<td></td>
</tr>
<tr>
<td>External bore of piston</td>
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<td>mm</td>
<td></td>
</tr>
<tr>
<td>Stroke stroke A</td>
<td></td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Stroke stroke B</td>
<td></td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

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Closed Loop System Performance

- When Performance is Critical, Use Simulation to Confirm Proper Valve Selection and System Design
- Evaluate System
- Collect Machine Information (RE 08 200)
- Hyvos Simulation Might Be Needed to Confirm Design for Critical Applications
Thank You