Hydraulic Power Recovery System

Western Michigan University
ME4800
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Abstract

Wasted power during testing and development of fluid power components is a major concern due to the negative environmental impact and overall associated energy costs. Dynamometer loading needed to simulate actual component field use results in this power loss. A concept for recouping this loss was developed, modeled, and tested. This energy recovery concept has application for both developmental testing and final production component validation.
Project Background

- FEMA Engineering Lab
  - New 300+ hp test stand in design stage
  - Durability Test Stands used to validate valve performance
  - Long-term cyclic testing of electro-hydraulic valves
  - Simulation of field operation in controlled setting
  - Relief valves used to simulate equipment loads
Using relief valve to build system pressure or simulate a load converts hydraulic kinetic energy into heat.

Significant energy lost to heat in new test stand.

**Design Problem:**
Develop an efficient and green method to recover energy lost in relief circuit.
Heat Recovery Concept

- Use heat from relief circuit to heat building in winter months
- Research alternate use when heat is not needed
Building 6 Heating

- Research heating sources in Building 6
- Furnace accounts for fraction of heat > 0.6%
<table>
<thead>
<tr>
<th>Heat Recovery Review</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>• No need to convert energy</td>
</tr>
<tr>
<td>• Does not affect test cell</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>• Uses small fraction of wasted energy</td>
</tr>
<tr>
<td>• Requires ventilation of excess heat</td>
</tr>
<tr>
<td>• Large capital investment</td>
</tr>
<tr>
<td>&gt; Ductwork</td>
</tr>
<tr>
<td>&gt; Employee safety</td>
</tr>
<tr>
<td>• Only effective part of year</td>
</tr>
</tbody>
</table>
Alternative Method:

Reduce amount of heat lost to environment

Apply energy in other forms
A high-powered test can be performed with little energy consumption by the drive motor.

In transmission testing, all energy stays in rotational form.

Energy in a hydraulic durability test changes states several times.
Pressure Series Accumulator Circuit

Standard Circuit:  \[ \text{Pump Demand} = \sum \text{valve demand} + \text{friction losses} \]

PSAC:  \[ \text{Pump Demand} = 1 \text{ valve demand} + \text{friction losses} \]

1. Displacement Pump
2. Check Valves
3. Customer Direction Control Valve
4. Accumulator
5. Flow Meter
6. Pressure Gauge
<table>
<thead>
<tr>
<th>Accumulator Series Pressure Circuit</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low capital investment</td>
<td>Need multiple valves on test</td>
</tr>
<tr>
<td></td>
<td>Highly efficient components (95%)</td>
<td>Increases length of durability test</td>
</tr>
<tr>
<td></td>
<td>Ease of maintenance</td>
<td>Synchronization of cycle timing</td>
</tr>
<tr>
<td></td>
<td>Few moving parts</td>
<td>Highly specific application</td>
</tr>
</tbody>
</table>
Hydraulic Generator Circuit

1. Variable Displacement Pump
2. Check Valves
3. Customer Direction Control Valve
4. Accumulator
7. Relief Valve
8. Electric Motor
9. Pressure Regulator
10. Hydraulic Motor
11. Generator
Hydraulic Generator Circuit

- Use hydraulic motor in place of relief valve
  - Relief valve used as safety/maintain pressure
  - Motor smaller displacement than pump in order to build pressure
- Hydraulic motor coupled to generator
- Generator wired to grid with grid-tie inverter
## Hydraulic Generator Circuit

<table>
<thead>
<tr>
<th>Cons</th>
<th>Pros</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many moving parts, energy produced can be used anywhere in the company, directly lowers cost of electricity, versatility - suitable for many applications</td>
<td>Versatile - suitable for many applications, directly lowers cost of electricity</td>
</tr>
<tr>
<td>Efficiency losses, change of state, high capital investment, generator efficiency (65%)</td>
<td></td>
</tr>
</tbody>
</table>
Final Design: Closed Loop Power Recovery

1. Variable Displacement Pump
2. Check Valves
3. Customer Direction Control Valve
4. Flow Meter
5. Pressure Gauge
6. Relief Valve
7. Electric Motor
8. Generator
9. Tachometer
Closed Loop Recovery

- Feeds generated power directly into test loop
- Motor acts as pump when system is not engaged
- Reduces current drawn by electric motor
- Fewer moving parts
- Higher efficiency
- Compact system
Simulation: AMESim
AMESim

- Circuit simplified for simulation
  - Motor coupling simulated by prime mover
  - Check valves not necessary for simulation

- Output:
  - Hydraulic performance
  - Power consumption
Motor Sizing

- **Maximum power output:**
  - Function of motor displacement
  - \( V_{\text{motor}} = V_{\text{pump}} \times \eta_{v,\text{pump}} \times \eta_{v,\text{motor}} \)
  - System pressure and RPM are constant
Relief Valve – 35cc Motor

- System produces max power with minimum flow across relief
- Flow rate when active = 10.30 LPM
- Flow rate when inactive = 81 LPM (full flow)
Power Recovery

- Power Input (Standard) = 25.08 kW
- Net Power (Recovery Active) = 10.95 kW – 56% recovered
# Budget Breakdown

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Catalog</th>
<th>Part Name</th>
<th>Quantity</th>
<th>Cost</th>
<th>BOM Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>59595K12</td>
<td>McMaster-Carr</td>
<td>Bladder Style Accumulator</td>
<td>1</td>
<td>$723.15</td>
<td>1 gal capacity, 150 gpm max</td>
</tr>
<tr>
<td>5843T25</td>
<td>McMaster-Carr</td>
<td>Sure-Seal Steel Check Valve</td>
<td>2</td>
<td>$49.91</td>
<td>Pipe is 3/8 in., Male inlet/outlet, 3000 psi max</td>
</tr>
<tr>
<td>5PZK4</td>
<td>Grainger</td>
<td>Eaton 103-1573-012 Hydraulic Motor</td>
<td>1</td>
<td>$489.25</td>
<td>3.6 cu in/rev, 2500 psi max</td>
</tr>
<tr>
<td>4UA85</td>
<td>Grainger</td>
<td>Eaton Relief Valve, 7/8-14 In UNF-2B Port</td>
<td>1</td>
<td>$446.25</td>
<td>45 gpm max flow, 1500-3000 psi range</td>
</tr>
<tr>
<td>4CFK8</td>
<td>Grainger</td>
<td>Ashcroft Digital Gauge/Transmitter</td>
<td>2</td>
<td>$511.00</td>
<td>3 in dial size, 3000 psi</td>
</tr>
<tr>
<td>4352K641</td>
<td>McMaster-Carr</td>
<td>High Accuracy Digital Flowmeter</td>
<td>2</td>
<td>$316.59</td>
<td>3-50 gpm range, 300 psi max</td>
</tr>
<tr>
<td>6136K414</td>
<td>McMaster-Carr</td>
<td>NEMA 143T/145T Base-Mount AC Motor</td>
<td>1</td>
<td>$462.84</td>
<td>3 phase, 3 hp, 3600 rpm</td>
</tr>
<tr>
<td>2905K41</td>
<td>McMaster-Carr</td>
<td>Pump-to-NEMA Motor Adapter</td>
<td>1</td>
<td>$33.42</td>
<td></td>
</tr>
</tbody>
</table>

**Total: $3,909.91**
Investment Recovery

- Test run time
  - 365 days, 8 hours per day
- Cost of industrial rate of electricity
  - $0.065 per kWh
- Total cost to run without recovery
  - $49,537.90
- With 50% recovery
  - $24,768.90
- Initial investment is recovered in 59 days
Conclusion

- Closed-loop Recovery is an effective method to simulate load and reduce power consumption
- Optimal replacement for relief valve to create line pressure
- With steady input, reduces power requirement by 50%
  - Depending on system friction & line losses
- Development needed to apply to cyclic testing
Continuation

- Test scale model before investing in full-size system
  - Dedicated lab testing

- Apply system to cyclic testing
  - Accumulator required to balance pressure spikes
  - Motor acts as pump during “off” (inactive) phase
    - Consumes energy
    - Sprag clutch? – Decouples from electric motor when no torque is applied