Increased energy efficiency of hydraulic hybrid drives by means of a multi-chamber accumulator

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Abstract
The focus of the present contribution is hydraulic energy recovery by means of hydropneumatic multi-chamber accumulators. A simulation study is presented comparing two different multi-chamber accumulator concepts for energy recovery in an exemplary load case involving a forklift mast. The first concept is based on the “Double Piston Accumulator” /1/. It is compared to the so-called “Digital Accumulator” /2/. Both similarities and differences of the two concepts are discussed in the presentation.

KEYWORDS: energy efficiency, hydraulic hybrid, multi-chamber accumulator

Information
Due to corporate reasons at this position the abstract is printed only. The complete contribution will follow in the online publication of the proceedings.

References


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Abstract
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KEYWORDS: energy efficiency, hydraulic hybrid, multi-chamber accumulator

1. Short presentation
Hydraulic Hybrids – Success of a proven, cost-effective Technology

- What are the reasons for the success of hydraulic hybrid technology?
  - robustness and reliability of the components
  - existing hydraulics on the machines / wide experience with hydraulics of the OEMs
  - high service-ability of the hydraulic systems and components
  - high power density of the components like accumulators and motors/pumps
  - easy packaging of the hydraulic accumulators
  - usage of proven, cost-effective components

Multi-Chamber Accumulator Concepts

- Using multi-chamber accumulators for hydraulic energy storage and recuperation
- The variation of the ratio between gas pressure and oil pressure yields two main advantages:
  1. Adapting the accumulator to the load pressure characteristic reduces throttling losses.
  2. The ability to transform the gas pressure to higher oil pressures enables direct recuperation of the energy stored in the accumulator.

- Two types of accumulators:

  The „Double Piston Accumulator“ (DPA) /1/  
  The „Digital Accumulator“ (DigiAccu) /2/
Simulation Study: Setting

- demonstrative test case: a forklift mast
- extreme case: load pressure is virtually constant
- lowering and lifting a constant load mass
- final lifting height is a measure for potential energy recovery
- Double Piston Accumulator vs. Digital Accumulator
- load control with pressure-compensated throttling valves
- physical model parameters from experimental investigations (cf. /3/)

Simulation Model

- AMESim model for the DPA case
- co-simulation using Matlab/Simulink and AMESim
  - physical model in AMESim
  - control in Simulink

DPA | Matlab/Simulink Interface | Mast
---|---|---

load mass
\[ m = 2500 \text{ kg} \]
\[ \Delta h = 6 \text{ m} \]

Cylinder
\[ \Delta V = 101 \text{ l} \]
\[ \phi = 2 \times 46 \text{ mm} \]
\[ r_{max} = 3 \text{ m} \]
\[ P_{max} = 147 \text{ bar} \]
Accumulators „under test“

The „Digital Accumulator“
- steady state pressure ratios: $p_{\text{gas}} : p_{\text{oil}} \in \left\{ \frac{4}{15}, \frac{5}{15}, \ldots, \frac{15}{15} \right\}$
- binary coded oil chambers
- total gas volume: 27.5 l
- pre-charge pressure: 50 bar
- max. design pressure: 210 bar

The „Double Piston Accumulator“
- steady state pressure ratios: $p_{\text{gas}} : p_{\text{oil}} \in \left\{ 1 - \frac{d_1^2}{d_2^2}, 1 - \frac{d_2^2}{d_3^2} \right\}$

**Variant 1**
- total gas volume: 27.5 l
- pre-charge pressure: 165 bar
- max. design pressure: 350 bar

**Variant 2**
- total gas volume: 18.5 l
- pre-charge pressure: 110 bar
- max. design pressure: 350 bar

Simulation Study: Results

- DigiAccu
  - final lifting height: 3.21 m
  - potential energy recovered: 54%

- DPA 27.5 l
  - final lifting height: 3.18 m
  - potential energy recovered: 53%

- DPA 18.5 l
  - final lifting height: 3.06 m
  - potential energy recovered: 51%
Conclusions

- Results:

<table>
<thead>
<tr>
<th>Type</th>
<th>Energy recovery</th>
<th>Length</th>
<th>Diameter</th>
<th>Space</th>
<th># Valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPA 27.5 l</td>
<td>53%</td>
<td>930 mm</td>
<td>355 mm</td>
<td>92 l</td>
<td>4</td>
</tr>
<tr>
<td>DPA 18.5 l</td>
<td>51%</td>
<td>850 mm</td>
<td>355 mm</td>
<td>81 l</td>
<td>4</td>
</tr>
<tr>
<td>DigiAccu</td>
<td>54%</td>
<td>1080 mm</td>
<td>355 mm</td>
<td>107 l</td>
<td>8</td>
</tr>
</tbody>
</table>

- The performance of the DPA is on par with the DigiAccu for the given test case.
  - Reason 1: Hydraulic losses due to frequent (de-) compression in the DigiAccu
  - Reason 2: Transformation to higher gas pressures in the DPA

- The DPA requires less mounting space (even without the valve manifold required).

- The geometry of the DPA is significantly less complex and requires less production expenditure.

- The basic principle of the DPA is proven in application.

- Main advantage of the DigiAccu: more flexibility to adapt to varying loads.

Hybrid Approaches and Benefits with HYDAC’s hybrid Solutions & Components

Hybrid approach
- Energy recovery
- Roost operation
- Downsizing
- Peak Shaving
- Best point operation
- Hydraulic start-stop
- Load compensation

Benefits
- Fuel savings
- Less exhaust
- Lower expenditure on exhaust after-treatment
- Noise protection
- Reduction of wear
- Increase of productivity
2. References

