Modeling of the Pneumatic Strain Energy Accumulator with Efficiency Increase Projections

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Overview of Pneumatic Strain Energy Accumulator

- Background
- Motivation: Previous Work
- Pneumatic Application Extension
- pSEA Component Efficiency Model
- Component Efficiency Experimental Results
- pSEA System Efficiency Model
- System Efficiency Input Parameters
- Future Work
- Summary
Background and Motivation

Pneumatic Strain Energy Accumulator fully realized on Ankle Foot Orthosis Device while challenges remain on hydraulic version.

Strain Energy Accumulator Pressure Volume Curve

Reported 25-75% Increase in Device Efficiency w/ pSEA

Hydraulic Accumulator

Primary Challenges:
- Materials
- **Modeling**
- Manufacturing
Pneumatic Application Extension

- Exhaust Gas Recycling Associated Project Started
- Identified new manufacturing end user partner for case study
- Constructed low pressure pneumatic strain energy accumulator for demonstration and future testing in manufacturing equipment

Manual Demonstrator

Quick Disconnect pSEA
pSEA Component Efficiency Model

- Pneumatic Strain Energy Accumulator Component Efficiency

\[ \eta_{acc} = \frac{\int_{V_o}^{V_{full}} \left( PdV + P_{\text{max}} V_{\text{full}} \ln \left( \frac{P_{\text{max}}}{P_{\text{atm}}} \right) \right)}{\int_{V_o}^{V_{full}} PdV + P_{\text{max}} V_{\text{full}} \ln \left( \frac{P_{\text{max}}}{P_{\text{atm}}} \right)} \]

Accumulator CV Definition

Experimental Test Setup

Pressure Volume Curve of pSEA
**pSEA Component Efficiency Model**

- Component efficiency equation used to find accumulator efficiency
- Uncertainty analysis used to determine mean and standard deviation of accumulator efficiency
- Accumulator is consistently above 93% during steady state

### Strain Energy Accumulator Component Efficiency

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mean (%)</th>
<th>Standard Deviation</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>93.35</td>
<td>0.063</td>
</tr>
<tr>
<td>2</td>
<td>93.32</td>
<td>0.057</td>
</tr>
<tr>
<td>3</td>
<td>93.42</td>
<td>0.050</td>
</tr>
<tr>
<td>4</td>
<td>93.42</td>
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<tr>
<td>5</td>
<td>93.39</td>
<td>0.048</td>
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<tr>
<td>5 Cycle Average</td>
<td>93.38</td>
<td>0.068</td>
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</table>

**Uncertainty Analysis: Mean and standard deviation of pSEA**
pSEA System Efficiency Model

• System Efficiency Increase with Incorporation of pSEA

\[ m_i = \frac{P V_i}{RT} \]

\[ \eta_{sys} = \frac{P_S}{P_S + \alpha \beta P_{exp}} \]

\[ \% Efficiency Increase = (1 - \eta_{sys}) \times 100 \]
pSEA System Efficiency Model

- Experimentally determined expansion and contraction pressure
- Serve as input to system state efficiency model
- Determined by averaging data from constant pressure regions
- Asymptotically approach steady state final value

Expansion and Contraction Pressures

Energy Input and Output
pSEA System Efficiency Model

- Linear regression analysis performed with coefficient of determination values reported for Trial 5 since approaches SS value
- Change in pressure over time very minimal

<table>
<thead>
<tr>
<th>Trial</th>
<th>Expansion</th>
<th>Contraction</th>
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<tbody>
<tr>
<td></td>
<td>$R^2$</td>
<td>$S_{Y</td>
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<tr>
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<td>5</td>
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<td>0.0656</td>
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</tbody>
</table>
Future Work

• Complete Automated System Setup
• Validate System Efficiency Model
• Provide Experimental System Efficiency Increase Measurements

• Fix End Connections and Conduct Fatigue Life/Cycle Life Testing
Summary

• Component efficiency model developed for pSEA

• pSEA component efficiency experimentally determined to be over 93% during steady state operation

• State system efficiency model developed for integration of pSEA component into dual actuator, single pSEA system

• Input parameters to system efficiency model experimentally determined from component efficiency testing

• System efficiency testing underway with results expected soon

• Future design work necessary to prior to conducting fatigue/cycle life testing to determine component reliability