Seamless Electric to Hydraulic Conversion

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Motivation

• Electric $\rightarrow$ Hydraulic Conversion
  – Push for electrification
  • Mobile and Industrial Systems

Conventional Approach:
- Stored Electricity
  - Rotating Mechanical
    - Pump Mechanism
      - Piston
        - Hydraulic Output

Proposed Approach:
- Stored Electricity
  - Piston
    - Hydraulic Output

Concentric hydraulic power unit
Prior Work

• Human Power Scale
• Electro-Hydraulic Actuation (EHA)

Proposed Concept

- Charge Pump in hydrostatic transmission (HST)
  - Direct electric control good for lower pressure, high frequency application
  - Variable displacement
Modeling

• Piston Dynamics
  – Forces acting:
    • Magnetic Force (input force)
    • Pressure
    • Spring
    • Viscous
  – Leakage Flowrate
Modeling

- Cylinder
  - Pressure Dynamics
  - Bulk Modulus
    - Pressure Dependent
Modeling

- **Check Valve Dynamics**
  - Forces acting:
    - Pressure
    - Spring
    - Damping

- **Flowrate**
  - Orifice Equation
Optimization

- Parameters being optimized:
  - Piston Diameter
  - Piston/Cylinder Gap Height
  - Check Valve Radius
  - Check Valve Spring Constant
  - Check Valve Cracking Pressure

- Objective function:
  \[
  \eta = \frac{E_{out}}{E_{in}} = \frac{\int \Delta P Q_{out}}{\int F v}
  \]

- Single Objective Genetic Algorithm
Results - $f = 50$ Hz

*Efficiency* = 98.03%

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piston Diameter</td>
<td>5.7 mm</td>
</tr>
<tr>
<td>Gap Height</td>
<td>15.7 μm</td>
</tr>
<tr>
<td>Disc Radius</td>
<td><em>inlet</em>: 10 mm</td>
</tr>
<tr>
<td></td>
<td><em>outlet</em>: 6.4 mm</td>
</tr>
<tr>
<td>Spring Constant</td>
<td><em>inlet</em>: 53.9 N/m</td>
</tr>
<tr>
<td></td>
<td><em>outlet</em>: 213.8 N/m</td>
</tr>
<tr>
<td>Cracking Pressure</td>
<td><em>inlet</em>: 1.00 kPa</td>
</tr>
<tr>
<td></td>
<td><em>outlet</em>: 1.00 kPa</td>
</tr>
</tbody>
</table>
Linear Electric Machine Topology

• Selected topology – tubular permanent magnet motor:
  o Effective use of the volume
  o Radial forces are cancelled
Linear Electric Machine Topology

• FEA model of the motor is developed:

• Using solid iron core generates eddy current losses.
• Alternative: laminations or soft magnetic composite.
1. Laminations – thin iron sheets:
   • Iron sheets parallel to the magnetic field flow.
Manufacturing Technique 2

2. Soft magnetic composite (SMC):

- Ferromagnetic powder particles coated with a uniform layer of electrical insulating film.
- Performance comparable to the iron lamination.

Electric Machine Optimization

Design specifications:
• Output power = 1.1 kW
• Output pressure = 2.7 MPa

Objectives:
• Maximize efficiency (\(\eta\))
• Minimize total cost
• Minimize force ripple (FR)

Number of variables: 13
Sample Optimal Design

Square wave current:

\[ f = 20 \text{ Hz} \]
\[ \text{stroke} = 23.7 \text{ mm} \]
\[ \eta = 89.9\% \]

Force vs. mover position for different currents:

- \( I = 13 \text{ A} \)
- \( I = 6.5 \text{ A} \)
- \( I = 0 \text{ A} \)
- \( I = -6.5 \text{ A} \)
- \( I = -13 \text{ A} \)
Electric Machine Optimization

Higher frequency:
- Higher efficiency.
- Lower machine materials cost.

Pareto fronts:

bore-to-stroke ratio = 1
Conclusion

• Candidate designs with efficiencies around 90% can be obtained.
• There is a trade-off between the efficiency of the motor and the pump when frequency increases.
• There are separate models developed for electrical and mechanical parts – getting ready to integrate these models.
Future Works

- Select appropriate oscillation frequency.
- Develop combined electrical and mechanical model.
- Construct a physical prototype system.
- Experimentally validate the models.
Thank you

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