A Hydraulic-Alternator System for Ocean Submersible Vehicles

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Outline

- Introduction
- System design
  - Hydraulic motor
  - Alternator
- Test results
  - Laboratory test results
  - Submersible vehicle measurement data
- Conclusions
Introduction

- Ocean floating instruments to monitor ocean climate
- Power is a major limitation

Argo Program:
3000+ floating instruments
Alternative technology for power generation

Temperature Difference  ➔  Volume Change  ➔  Pressure Difference

- Phase change material (PCM)
  - Expands/contracts as it encounters warm/cold waters at ocean surface/depth
  - Creates a pressure difference that drives a hydraulic motor – alternator
- Generated electric power stored in batteries
- Renewable energy system

Battery Recharging
System design

- Hydraulic motor serves as prime mover to 3-phase synchronous generator
- Gearbox matches speeds of motor – alternator
- 3-phase full wave rectifier converts ac power to dc for recharging Li-Ion battery
- Shunt regulator diverts any excess power
- Emphasis on system efficiency improvement
  - Specifically, hydraulic motor – alternator efficiency
Hydraulic motor

- Overall efficiency: \( \eta_o = \eta_m \eta_v \)
- Volumetric efficiency: \( \eta_v = \frac{Q_{\text{actual}}}{Q_{\text{theoretical}}} \)
  - Flow \( Q \) in m\(^3\)/s
- Mechanical efficiency: \( \eta_m = \frac{\tau_{\text{actual}}}{\tau_{\text{theoretical}}} \)
  - \( \tau \) in N-m
- \( V \): displacement in m\(^3\)/rev \( Q = V \ n \)
  - \( N \): speed in rev/s
- \( \Delta p \): pressure drop in N/m\(^2\) \( \tau = V \ \Delta p \)
- Gear motor: fixed displacement
- Efficiency of hydraulic motor expected to increase with speed and pressure drop
- Efficiency tapers off due to leakage and mechanical losses
Alternator

- **Speed – Torque characteristics**
  - $W_{nl}$: no load angular velocity in rad/s $w_{nl}$
  - $T_s$: stall torque
- **Mechanical power**
  - Max. power at $T_s / 2$
- **Efficiency**
  - $I_{nl}$, $I_s$: no load and stall currents

\[
\omega = \frac{\omega_{nl}}{T_s} (T_s - T)
\]

\[
P = \omega_{nl} T - \frac{\omega_{nl}}{T_s} T^2
\]
Test Setup

- Fill tank with oil and pressurize
- Open valve to allow for pressure drop across hydraulic motor
### Sample Lab Test Results

#### Hydraulic Motor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆p</td>
<td>2,195 psi (or 1.5 x 10^7 pa)</td>
</tr>
<tr>
<td>Q</td>
<td>1.2 GPM (or 7.5 x 10^-5 m^3/s)</td>
</tr>
<tr>
<td>Speed</td>
<td>1,554 rpm</td>
</tr>
<tr>
<td>$P_{in} = Q \Delta p$</td>
<td>1,136 W</td>
</tr>
</tbody>
</table>

#### PM Alternator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>6,216 rpm</td>
</tr>
<tr>
<td>$V_{LN}$</td>
<td>21.5 V</td>
</tr>
<tr>
<td>$I_{line}$</td>
<td>10.2 A</td>
</tr>
<tr>
<td>$P_{out} = 3 V_{LN} I_{line}$</td>
<td>655 W</td>
</tr>
</tbody>
</table>

#### System Efficiency

| Efficiency       | 58%              |

#### Overall power efficiency is 0.58
Deployment of integrated vehicle in ocean

- 84 kg vehicle
- 1000 dives between surface and 500 m
• 1.7 W-hr generated per cycle
• Sufficient to provide vehicle power needs
Conclusions and recommendations

• Hydraulic motor – alternator system built and tested
  – 58% efficiency achieved in lab
• Successful submersible vehicle operation demonstrated in ocean
• Recommend further optimization of system
  – Custom design and build hydraulic motor – alternator set
    • Match torques of motor and alternator to eliminate the need for a gearbox
    • Design system for maximum efficiency (or minimum losses) under rated conditions