AIP Technologies/Stored Energy Devices

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Air independent propulsion (AIP) for Diesel-electric class of Submarines

AIP: Additional power plant added to the Diesel-Electric submarine for extending the underwater endurance.

Conventional mode
- Battery charging by Diesel generators
- Underwater propulsion on Battery

AIP mode
- Battery charging by Diesel generators
- Underwater propulsion on AIP
- Resurfaced for battery charging (Snorkeling mode)

Snorkeling mode of submarine – most vulnerable phase
- Extending Time for resurfacing
- Time for resurfacing
The AIP ........

- It is a non-nuclear alternative
- Longer endurance under submerged condition by supplementing the lead acid batteries
- Provides higher stealth (acoustic silence) characteristics underwater
- Reduces the risk of exposure by avoiding frequent surfacing
How AIP works……..

Objective :- to preserve battery power while underwater
Comparison of global AIP technologies

• Closed cycle Diesel (CCD) – Russia – (*****)
  – Noisy, discarded by the modern Navy
• Steam alternator MESMA – France (*****)
  – Noisy, exported to Pakistan Navy
• Sterling engine – Sweden {*****}
  – Adopted in Kockum class and technology exported to China
• Fuel cell system {*****}
  – Metal hydride / PEMFC – Germany (used by many countries)
  – Diesel reformer/ AFC – Russia – prototype level
  – Diesel reformer / PEMFC – France | Spain – prototype level
  – Borohydride / PAFC – DRDO India – prototype level (advanced)

(***** Ratings based on AIP efficiency, low signature and safety)
# Selection of Hydrogen-Oxygen Fuel Cells...a trade off

<table>
<thead>
<tr>
<th>Fuel Cell Types</th>
<th>Efficiency</th>
<th>Life</th>
<th>Size</th>
<th>Reactant quality required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkaline Fuel Cells (AFC)</td>
<td>High 🟢</td>
<td>Poor ✗ &lt; 2000 hrs</td>
<td>medium ✓</td>
<td>Ultra high purity ✗</td>
</tr>
<tr>
<td>Polymer Electrolyte Fuel cells (PEMFC)</td>
<td>Medium ✓</td>
<td>Medium &lt; 5000 hrs</td>
<td>small ✓</td>
<td>High purity ✗</td>
</tr>
<tr>
<td>Phosphoric Acid Fuel Cells (PAFC)</td>
<td>Medium ✓</td>
<td>High &gt; 45000 hrs</td>
<td>big ✗</td>
<td>Low purity ✓</td>
</tr>
<tr>
<td>Solid oxide fuel cells (SOFC)</td>
<td>Technology under development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molten Carbonate fuel Cells (MCFC)</td>
<td>Technology under development</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
# Onboard Hydrogen storage/generation

## Primary driver

<table>
<thead>
<tr>
<th>Technology</th>
<th>Additional LOX compliment</th>
<th>Gaseous effluent (cause noise)</th>
<th>Life</th>
<th>Hydrogen qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal hydride</td>
<td>Nil ✓</td>
<td>Nil ✓</td>
<td>Low ✗</td>
<td>Low ✗</td>
</tr>
<tr>
<td>Diesel Reforming</td>
<td>High ✗</td>
<td>High ✗</td>
<td>Uncertain</td>
<td>Medium ✓</td>
</tr>
<tr>
<td>Methanol reforming</td>
<td>Low ✓</td>
<td>Low ✓</td>
<td>High ✓</td>
<td>high ✓</td>
</tr>
<tr>
<td>Borohydride hydrolysis</td>
<td>nil ✓</td>
<td>nil ✓</td>
<td>high ✓</td>
<td>high ✓</td>
</tr>
</tbody>
</table>
NMRL competence in fuel cells technology

- **Materials for Phosphoric acid fuel cells (PAFC)**
  - Complete material solutions for PAFC 1996-1998
    - Catalyst, moulded graphite bipolar plate, carbon paper, sealants, acid holder matrix etc. (innovations patented)
    - Indian Industry partner developed for all materials

- **Fuel cell Stack 1998-2003**
  - PAFC stacks 1-3kw
  - PAFC technology for production transferred to industry

- **Fuel cell power plant 2003-2009**
  - Compact packaged methanol reformer for fuel cell Field use (any fuel cell) with filters if required upto 15kw power plant
Upgradation of Fuel cell Stacks for Marine grade ruggedization & Compaction

- 6kw, N6 (2011)
- 9kw, N9
- 11.5 kw, N11
  - Rugged cocoon

Knowhow transferred to Industry partner & is completely industrialized
Possible to use upto 500kw power generation by series/parallel connection
Air Independent Propulsion (AIP) Technology Conceptualized & Developed in NMRL

- Present system configuration is customized for P-75 Submarines;
- Flexible modular design approach allows adaptation to any submarine – new or retro fitment

In-house developed Fuel Cell: PAFC & H2 generator

- NaBH4 + H2O = NaBO2 + 4H2
- H2 + 1/2O2 = H2O + Power

NaBH4 solution (aq)
NMRL developed Fuel Cell AIP for integration to ongoing P-75 Submarine

- Fuel Cell based AIP is integrated in an additional section (AIP plug) and inserted to the Submarine
- Open architecture plant proven
- Prototype conforming to Submarine stds. Under advanced phase of development
Novel H2 Provision for futuristic FC based AIP

- Ammonia electrolysis
  - Advantages
    • Small fraction of power required for splitting ammonia
    • Quick startup and simple system
    • Highly suitable for very long endurance
  - Challenges
    • Safety solution for carrying pressurised fuel
    • Noise reduction due to Nitrogen (by-product) bubbling out

- Al / Gallium liquid metal alloy based generator
  - Advantages
    • Quick startup and pumpable liquid alloy (>40°C)
    • All solid by products, possible to contain within submarine
  - Disadvantages
    • Safety solutions for explosive reaction with water in case of storage breach
Polymer based electrochemical super capacitors with very high capacitance and high power density, excellent cycle life.

- **Configuration**
  - Capacitance: 100 F-1000 F
  - Voltage: 0-2.5 V (Vmax:2.75 V)
  - ESR: 15 to 35 m ohm
  - Operating Temp.: -40 to 55 °C

- **Applications**
  - Fuel cells
  - Sonar
  - Telecommunication systems
  - Portable Power Pack Systems
  - Cranking of engines
  - Electric vehicle

- **Status:**
  - Technology available for transfer
THANK YOU