Anode and Cathode Blower Systems for SOFC

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Agenda

• PADT Background
• Summary of HARB program
• Transition from DG to FutureGen
• HARB II for FutureGen
• Component Development
• New blower: Small Multi-stage (SMS) blower
• Conclusions
Who is PADT?

• Incorporated in March 1994
  – Specialty blowers
  – Simulation services
  – Rapid prototyping
  – Medical instruments
  – Semiconductor equipment

  – Facilities
    – 24,000 ft² at ASU Research Park in Tempe, Arizona
    – 60% Office
    – 40% Shop & Lab

• People
  – 50 Employees
PADT Fuel Cell Programs

1998-2000
• 5 Roots Cathode blowers delivered
• 6 Axial Cathode blowers delivered

2001-2002
• VGEN, TURBOMIX, TRILOBE designed
• 18 blowers delivered

2003
• 28 blowers delivered

2004
• New HRB, SECA, TURBORAD developed
• 60 blowers delivered

2005
• HARB developed
• 120 blowers delivered

2006
• MINIRAD developed
• 150 blowers delivered
Summary of HARB Development

• Hot Anode Recycle Blower (HARB)
  • HARB I POC built and tested
    – Thermal segregation proven
    – Tested to ~ 600 C
    – Low efficiency, ~ 25%

• Transition to FutureGen
  – Program slowed down
  – Specifications reassessed

• Component development
  – BLDC Motor
  – Bearings
  – Pumphead evaluation

• HARB II Designed for FutureGen
FutureGen Approach: HARB II

- Consulted with most SOFC developers
  - Support from DOE
- Design Drivers for FutureGen
  - Robustness
  - Cost Control
  - High performance
  - Flexible
- Approach for HARB II
  - 700 C inlet
  - Scalable, serves 50 kWe – 500 kWe
  - Low cost mfg processes
  - Moderate RPM 10k – 20k RPM
  - 18” long x 10” dia.
  - Good efficiency ~ 55%, DC to fluid
- Patents being evaluated
  - Pumphead, bearings, cooling
HARB II: Risk Assessment

• Motor exposure to High Voltage/Temperature/Moisture
  – Potting with silicone/epoxies/urethanes help some
  – Canned motor is best solution

• Motor Hall sensor failure
  – Work towards sensorless control
  – Keep sensors out of process flow

• Condensation in bearing/motor cavity
  – Anode gases are ~ 50% mole fraction H₂O
  – Bearing/motor cavity may be below dew point

• Bearing Failure
  – Continual progress is being made (e.g. SiN balls)
  – Proper mounting and lubrication

• Impeller Creep
  – Control temps and stress

• Pumphead Corrosion, Chromium contamination

• Feedback: High temps add more risk
HARB II: Cost Assessment

- Bottom up cost estimate complete for HARB II
  - Based on quotes, scales, and estimates

- Feedback: Cost Drivers
  - Pressure Rise drives cost, higher stage count
  - Also higher power levels drive motor/controller cost up
  - Big benefit if inlet temp is below 500C. Enable SS solutions

<table>
<thead>
<tr>
<th>SUMMARY OF HARDWARE COSTS</th>
<th>PERCENT</th>
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<tbody>
<tr>
<td>Cool static component costs</td>
<td>12%</td>
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<tr>
<td>Cool rotating component costs</td>
<td>11%</td>
</tr>
<tr>
<td>Hot static component costs</td>
<td>31%</td>
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<tr>
<td>Hot rotating component costs</td>
<td>14%</td>
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<tr>
<td>Motor/Controller costs</td>
<td>32%</td>
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</table>
HARB II: BLDC Canned Motor

- Motor now being tested in PEM based HRB system
- Cost Control
  - Keep RPM down
  - Avoid nickel-iron laminations
  - Use silicon steel laminations
  - Injection moldable can designs
- Testing in fuel cell environment
  - High temperature, Water, Hydrogen, Voltage
  - Pressure cycling for 38368 cycles over 632 hours
- Thermal Shock Testing
  - -40 C to 140 C, 300 cycles
- Overpressure to ~ 8 Bar with no issues
# HARB II: Motor Can Testing

## Fuel Cell Chamber

<table>
<thead>
<tr>
<th>Material</th>
<th>HIPPIES Test</th>
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<th>HIPPIES Test</th>
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<tbody>
<tr>
<td></td>
<td>Initial Test</td>
<td>304 hrs, 14199</td>
<td>632 hrs, 38368</td>
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<tr>
<td>Measured Leak Rate</td>
<td>Measured Leak Rate</td>
<td>Measured Leak Rate</td>
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<tr>
<td>Material (cc/sec) (cc/hr)</td>
<td>(cc/sec) (cc/hr)</td>
<td>(cc/sec) (cc/hr)</td>
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<tr>
<td>Ultem 30% filled</td>
<td>1.50E-05 0.054</td>
<td>2.40E-05 0.086</td>
<td>2.00E-05 0.072</td>
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<tr>
<td>Ultem (unfilled)</td>
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<td>3.10E-05 0.112</td>
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<tr>
<td>Peek (unfilled)</td>
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<td>1.20E-05 0.043</td>
<td>7.40E-06 0.027</td>
</tr>
</tbody>
</table>

## THERMAL SHOCK

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<thead>
<tr>
<th>Material</th>
<th>Thermal Shock</th>
<th>Thermal Shock</th>
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<tr>
<td></td>
<td>Initial Test</td>
<td>300 cycles</td>
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<td>Measured Leak Rate</td>
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<tr>
<td>Ultem 30% filled</td>
<td>1.50E-05 0.054</td>
<td>1.60E-05 0.065</td>
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<tr>
<td>Ultem (unfilled)</td>
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<tr>
<td>Peek (unfilled)</td>
<td>6.75E-05 0.243</td>
<td>8.20E-06 0.03</td>
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</table>
HARB II: Bearing Development

- 2 Bearing Rigs built
  - Running non-stop
- Accelerated life testing
  - Need 40000 hrs of life
  - 2 year program
- Working with industry veteran
  - 40 years of experience
- An additional 2 rigs now being built
  - 4 rigs total
Impeller Selection

• 4 Configurations considered
  – Cast regenerative
  – Cast single stage centrifugal
  – Single stage sheet metal centrifugal
  – Multi-stage sheet metal centrifugal

• Regenerative is inefficient
  – Axial clearance is critical
  – Temperatures, transients

• Cast approach slow/expensive
  – Got 2 Quotations (Howmet, Miller)
  – Casting cost over $2000 in low volume
  – Post machining greater than $2000
  – Long lead times, ~ 6 months
Impeller Selection

- Single stage sheet has high stresses
  - High tip speed required to make DP
  - Bore stresses exceed 30 ksi
  - Haynes 230 will have limited life
Multi-Stage Impeller Selected

- Multi-stage Impeller offers solution
  - Tip speed way down. Quiet.
  - Bore stresses lower than 10 ksi
  - Flexible: Stage count easy to change
  - Very low cost
- Efficiency proven on MINIRAD program
  - ~43% overall efficiency
  - Expect ~55% for HARB II
  - Patent under evaluation
New Developments

• PADT has chosen to split program
  – HARB II for FutureGen
  – Small Multi-Stage (SMS) blower for DG
  – Both blowers will use same pumphead technology
• HARB II now in final design
  – Hardware in ~ 6 months
• SMS Blower
  – Will provide anode recycle
  – ~ 200C
  – Same multi-stage approach
  – Same motor approach
  – Design restricted to very low cost mfg processes
  – Flexible
Acknowledgements

• SOFC developers

• NETL support
  – Chuck Alsup
  – Travis Schultz
  – Heather Quedenfeld

• UCI
  – Jack Brouwer

• Dawnbreaker Commercialization Assistance
  – Jenny Servo, Bob Larsen, Patty Heckman

• PADT Blower development team