Advanced Stirling Convertor Testing at GRC

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Background

Advanced Stirling Radioisotope Generator

• Next generation radioisotope-fueled power system
• Lockheed Martin Space Systems is System Integration Contractor
• Suitable for deep-space or other missions without solar power
• Two dual-opposed free-piston Stirling convertors
• > 20% thermal-to-electric conversion at system level
• 1st use of dynamic energy conversion in space
• Necessitates demonstration of conversion technology long-term performance
Background

Advanced Stirling Convertor

- Designed and Manufactured by Sunpower, Inc.
- Development initiated in 2004 via NASA technology development contract
- 6 stages of development:
  1. ASC-0
  2. ASC-1
  3. ASC-1HS
  4. ASC-E - First Engineering Unit design
  5. ASC-E2 - Engineering Unit design with high-temp heater head
  6. ASC-E3 - Pathfinder for Flight Unit production

ASC-E3 as-built hardware
Test Methodology

Three types of tests are performed:

1. Performance Mapping
   • Simulate range of expected operating temperatures
   • Max/Min thermal input, max/min sink temperature

2. Durability Tests
   • Demonstrate and quantify margin of ASC design
   • Start/stop cycling, static acceleration, launch vibration, overstroke

3. Extended Operation
   • Goal: 10s of thousands of hours
   • 24/7, unattended operation

Implementation

• Electric heat source for heat input
• Laboratory circulator for heat rejection
• Automated data system
• Automated shutdown routines
• Thermocouples, thermistors for temperature
• Power meters for voltage, current, power
• LabView data acquisition software
Test Article Design

Previous test article designs needed improvement:

- Unify convertor test configuration between Sunpower and GRC locations
- Reduce thermal insulation losses
- Eliminate radiation heat transfer paths for more accurate finite element modeling
- Improve temperature measurements for more accurate modeling
- Improve electric heat source life

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ASC-E2 Test Article Deficiencies

- Heaters protruded through insulation
- Air gaps (radiation heat transfer)
- Limited life heat source (~2500 hrs)
- Square housing (non-axisymmetric)
ASC-E3 Test Article

Improvements:

- Minimized heater lead losses
- Circular, axisymmetric insulation
- Air gaps filled with compressible insulation
- Longer life heat source (better cartridge fit, lower heat flux)
- Additional temp measurements throughout
ASC-E3 Temperature Measurements

- Auxiliary thermocouples are required for thermal model
- Embedded in insulation before assembly – more accurate placement
- Aligned with isotherms to reduce disturbance of object temperature

Example auxiliary thermocouple installed in microporous insulation piece
Placed along an isotherm to reduce local temperature disturbance
ASC-E3 Performance Measurement Instrumentation

- Heater Power Meter
- V+, V-
- DC Power Supply
- PID Temp Controller
- Heat Distributor
- Heat Source Temp TC probes
- Net Heat Input (calc)
- Hot End Temp TC probes
- Cold End Temp TC probes Thermistors
- Alternator Housing Temp Surface TCs Thermistors
- Alternator Power Meter
- V+, V-
- AC Bus Power Meter (variable freq.)
- AC Power Supply (variable freq.)
- Pearson Coils
- Capacitor
- Load
- Piston Position Sensor Processor
- 7 kHz
- High-rate voltage and current waveform archival
- High-rate piston position waveform archival
- ASC-E3 Performance Measurement Instrumentation
ASC-E3 Test Station

- Simultaneous operation of a pair of convertors
- Vertical orientation
- Independent operating condition control

Test Rack
- Data acquisition
- Monitoring
- Operating point control

2 Convertors
- Side-by-side
- Vertical orientation

Circulators
- Cold-end temp control
ASC-E3 Data Archival and Processing

- Centralized storage of data from all test stations
- All parameters measured and recorded every 2 seconds
- 5-minute-window average point stored each hour
- Dynamic data sampled and stored at 7 kHz
- Operator notes stored in an event log

Test Rack
- 6TB array RAID5

Data Server
- 20 TB array RAID5

Daily Transfer
- Ethernet
- 7 kHz data
- 50 GB/hr

Matlab plotting script
- Automated 24-hr plot generation
- User-customizable plotting options
- Automatic population of operator notes on time axis
- Automatic plot naming and storage
- Engineers can examine plots to analyze performance
ASC-E3 Operational Data

ASC-E3 #1 & #2 runtime each > 2,000 hrs

- No instabilities observed over a range of operating conditions
- No signs of heat source failure
- Daily 2-second data plots show steady operation
## ASC Operation Summary

<table>
<thead>
<tr>
<th>ASC Model</th>
<th># Units</th>
<th>Total Runtime</th>
<th>Status</th>
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<tbody>
<tr>
<td>ASC-0</td>
<td>4</td>
<td>92,000</td>
<td>Ongoing</td>
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<tr>
<td>ASC-1</td>
<td>2</td>
<td>3,700</td>
<td>Ongoing</td>
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<tr>
<td>ASC-1HS</td>
<td>2</td>
<td>11,000</td>
<td>Complete</td>
</tr>
<tr>
<td>ASC-E</td>
<td>4</td>
<td>100,000</td>
<td>Ongoing</td>
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<tr>
<td>ASC-E2</td>
<td>8</td>
<td>54,000</td>
<td>Ongoing</td>
</tr>
<tr>
<td>ASC-E3</td>
<td>2</td>
<td>4,000</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

Total = 263,900