Paraffin Actuated Heat Switch for Mars Surface Applications

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Overview

- Background
- Key Driving Requirements for a Heat Switch
- Paraffin Actuated Heat Switch
  - Heat Switch Design Features
  - Heat Switch Performance
  - Flight Qualification
- Mars Exploration Rover (MER) Application – Rover Battery
  - Rover Battery Thermal Control System
  - Thermal Control System Performance
- Summary
- Q&A
Background

**Unique Thermal Control Requirements for Mars Surface Applications**
- Diurnal temperature changes greater than 100 °C
- Presence of Mars atmosphere
- Need to minimize landed mass
- Power for active thermal control is scarce
  - Need to conserve energy at night
  - Need to reject excess heat during the day

**Variable Thermal Conductance Device**
- Passive, variable thermal conductance mechanism which can be mounted between a heat sink and heat source
- Variable thermal conductance achieved via temperature activated paraffin wax which expands/contracts to mechanically close/open the switch
Key design requirements for the heat switch were based on structural as well as thermal needs.

<table>
<thead>
<tr>
<th>Requirement Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch-Open Conductance</td>
<td>&lt; 0.018 W/K at 18 °C and lower</td>
</tr>
<tr>
<td>Switch-Closed Conductance</td>
<td>&gt; 0.45 W/K at 25 °C and higher</td>
</tr>
<tr>
<td>Heat Switch Assembly Mass</td>
<td>&lt; 160 g</td>
</tr>
<tr>
<td>Landing Loads (qualification)</td>
<td>48 Gs</td>
</tr>
<tr>
<td>Random Vibration (qualification)</td>
<td>7.8 Grms, 2 min./axis</td>
</tr>
<tr>
<td></td>
<td>(20-80 Hz: +6db/Oct.</td>
</tr>
<tr>
<td></td>
<td>80-450 Hz: 0.08 G²/Hz</td>
</tr>
</tbody>
</table>
Paraffin Actuated Heat Switch

STAF 2002

Design Features

- Developed by Starsys Research Corporation for JPL
  - Based on previous designs by Starsys with modifications to accommodate the Mars environment
- About 36 mm diameter x 51 mm in length
- Aluminum body, 110 grams
- Molded Viton seal encloses paraffin
- Temperature based expansion and contraction of the paraffin works to close and open the switch
  - switch activation temperature is selectable based on paraffin type
- Springs with insulating stand-offs provide force to open gap when paraffin freezes
• **Design Features (cont’d)**
  - Control is not simply by On-Off switching
    - thermal conductance adjusts to stable intermediate levels as required
  - Switch control is based on the temperature of the warm side of the switch
  - In switch-open state, two halves of switch are separated by a gap
    - heat conduction is limited to gas gap conduction and small parasitic leaks through stand-offs
  - In switch-closed state, the halves are pulled into contact with each other
    - heat is conducted through aluminum body across contacting surface
Paraffin Actuated Heat Switch

Heat Switch Shown in Closed State

- Attached to heat source
- Switch half containing paraffin seal boot
- In switch-open state, 1mm gap separates the two switch halves
- Attached to heat sink
MER Heat Switch Qual Performance Test Results, S/N 005

- Performance Test
- S/N 006 with Grease (Performance Test)

Heat Switch Warm Side Temperature (C) vs. Conductance (W/C)
The Starsys Heat Switch has Passed all tests and is Flight Qualified:

<table>
<thead>
<tr>
<th>Test Step</th>
<th>Heat Switch Unit (2 Units)</th>
<th>Notes</th>
<th>Wobblefram Seal (2 Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Seal Boot Hydraulic Life Cycle Test</td>
<td>Performed on seal boot taken from same lot as qual units</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Functional Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Belleville Washer Force Test</td>
<td>May be performed at any time during test sequence</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Functional Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Vacuum Bake-Out</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Vacuum Bake-Out</td>
</tr>
<tr>
<td>6</td>
<td>Performance Test</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Performance Test</td>
</tr>
<tr>
<td>7</td>
<td>Random Vibration Test</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Random Vibration Test</td>
</tr>
<tr>
<td>8</td>
<td>Pyrotechnic Shock Test</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Pyrotechnic Shock Test</td>
</tr>
<tr>
<td>9</td>
<td>Landing Loads Test</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Landing Loads Test</td>
</tr>
</tbody>
</table>
## Qualification Program (2/2)

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<tr>
<th>Test Step</th>
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<th>Notes</th>
<th>Wobblefram Seal (2 Units)</th>
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</thead>
<tbody>
<tr>
<td>10</td>
<td>Push/Pull Force Test</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Performance Verification Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Thermal Cycle Test</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Thermal Cycle Test</td>
</tr>
<tr>
<td>13</td>
<td>Performance Verification Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Thermal Life Cycle Test</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Thermal Life Cycle Test</td>
</tr>
<tr>
<td>15</td>
<td>Performance Verification Test</td>
<td></td>
<td>Performance Test</td>
</tr>
<tr>
<td>16</td>
<td>Dimensional Inspection</td>
<td>May be performed at any time during test sequence</td>
<td>Dimensional Inspection</td>
</tr>
<tr>
<td>17</td>
<td>Mass Inspection</td>
<td>May be performed at any time during test sequence</td>
<td>Mass Inspection</td>
</tr>
<tr>
<td>18</td>
<td>Visual Inspection</td>
<td>Heat Switch &amp; Wobblefram tested as an assembly</td>
<td>Visual Inspection</td>
</tr>
</tbody>
</table>
• Heat Switch used for the MER Rover Battery Thermal Control System
  – Battery allowable flight temperature limits:
    • surface ops (discharge): -20 °C to +30 °C
    • surface ops (charge): 0 °C to +30 °C
  – Diurnal environment temperatures:
    • Ground: -95 °C min to +20 °C max
    • Atmosphere: -95 °C min to 0 °C max
    • Sky: -150 °C min to -100 °C max
  – Heat sources
    • RHUs provide 6 W continuous
    • nearby electronics contained within same Warm Electronics Box
    • battery internal dissipation
    • thermostatically controlled survival and warm-up heaters, if necessary
Mars Exploration Rover (MER) Application

Variable Thermal Conductance Heat Switch
2 Places

HRS Tubing & I/F Plate

Tube Containing Qty. 3 RHUs
Constant Heat Source of ~ 3 W
2 Places

Warm-Up & Survival Heater Patch
4 Places

Warm-Up & Survival Mech.
Thermostats
Mounted to +Z
Side of RBAU – Not Shown

High Thermal Resistance Tube Struts
6 Places

External Radiator
~413 cm², 1 mm thick, Al 6061-T6
White Paint on Outward Face
Bare Al on Inward Face
2 Places
Maximum/Minimum Battery Cell Temperatures vs. L.M.S.T.

Comparison of latest model with and without gas conductance

Upper AFT = 30 °C
Min charge temp = 0 °C
Lower AFT = -20 °C
Maximum/Minimum Battery Cell Temperatures vs. L.M.S.T.

- Upper AFT = 30 °C
- Min charge temp = 0 °C
- Lower AFT = -20 °C
Application Performance – One Heat Switch Failed Open

Maximum/Minimum Battery Cell Temperatures vs. L.M.S.T.

Upper AFT = 30 °C
Min charge temp = 0 °C
Lower AFT = -20 °C

Heat switch failed closed unlikely
Summary

- Heat Switch has been flight qualified for use on the Mars Exploration Rover (2003 Launch)
  - Thermal performance exceeds requirements
  - Robust structural design permitted Switch to survive landing loads twice the requirement
- Flight units currently undergoing acceptance testing at Starsys