INTERPACK 99

Failure Engineering Study and Accelerated Stress Test Results for the Mars Global Surveyor Spacecraft’s Power Shunt Assemblies

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INTRODUCTION

- USE METHODOLOGY FOR IDENTIFYING DOMINANT FAILURE MECHANISMS
  - IDENTIFY SPECIFIC FAILURE MECHANISMS IMPACTED BY CHANGE IN MISSION REQUIREMENTS
  - IDENTIFY SPECIFIC TESTS/ANALYSES THAT COULD ASSESS THE RISK ASSOCIATED WITH NEW MISSION REQUIREMENTS

- DESIGN & PERFORM TESTS
  - DEFINE FAILURE MODELS FOR TALL POLE FAILURE MECHANISMS IDENTIFIED ABOVE
    - ACCELERATION PARAMETERS & LIMITS OF APPLICABILITY
MGS PSA POST-LAUNCH QUALIFICATION TEST DESIGN BACKGROUND

- POST LAUNCH FAILURE OF AN UNRELATED PART AFFECTS FLIGHT PLAN
- THE PREFERRED NEW PLAN INVOLVES THE ADDITION OF MANY DEEP THERMAL CYCLES TO THE POWER SHUNT ASSEMBLIES (PSA’S)
- NEW PLAN EXCEEDS:
  - PREVIOUS ACCEPTANCE COLD LEVEL (BY 45C)
  - FATIGUE LIFE DATA ON PACKAGING DESIGN

MGS S/C CRUISE CONFIGURATION

Set of 11 Power Shunt Assemblies on each solar array yoke
ENGINEERING PROBLEM & RELATED QUESTIONS

QUESTIONS:
- DOES THE ON-ORBIT HARDWARE HAVE SUFFICIENT LIFE TO SURVIVE THE NEW MISSION PROFILE?
- HOW CAN THIS BE ANSWERED POST LAUNCH?

NEEDS:
- FAST VERIFICATIONS/TEST(S) THAT WILL CONFIRM THE MOST LIKELY FAILURE MECHANISM(S) AND THEIR LIKELIHOOD OF OCCURRENCE DURING THE NEW MISSION

SOLUTION:
- VARIETY OF ANALYSES, SIMPLIFIED FAILURE MECHANISM MODELS MATERIAL PROPERTY MEASUREMENTS AND HIGHLY ACCELERATED TEST(S) THAT WILL VERIFY THE MOST LIKELY FAILURE MECHANISM(S) AND THEIR LIKELIHOOD OF OCCURRENCE DURING THE NEW MISSION
PSA HARDWARE DESIGN

PHYSICAL DESCRIPTION

• SHEET METAL HOUSING
• ONE DRIVE Tx,
• FIVE DRIVEN Tx (4 Redundant)
• PLUS ASSOCIATED R’s & C’s
• ALL PARTS HEAT SUNK DIRECTLY TO METAL HOUSING (i.e. NO CIRCUIT BOARD)

FUNCTIONAL DESCRIPTION

• PROVIDE REGULATION OF SOLAR PANEL POWER BY SHUNTING EXCESS POWER
• 11 PSA’s PER SOLAR PANEL
DRIVEN TRANSISTOR PACKAGING DETAIL

Close-up of driven transistor bonded to sheet metal housing. Note all external wire interconnects are coated with a dielectric (white material).

Posts are gold plated over Nickel. Threaded stud is made of copper that has been plated.

Figure 7. Top view of Transistors showing bondwire configurations. Bondwires are dead soft Aluminum 0.010 inches in Diameter on Aluminum metalization. Posts are Nickle. All are bonds ultrasonic. Bonds to die are orthodyne bonds while bonds to post are wedge bonds.

Emitter Post, Design uses Dual Emitters and redundant bondwires for each emitter.

Base Post, Single Base with redundant bondwires

Bondwires number 1-6 going counter clockwise starting here for Pull Test Data

Bondwire No. 6.

BeO Header bonded to head of copper stud, with gold metalization on top of header and gold eutectic die bond.
EXPERIMENT DESIGN

- DRIVEN BY PROCESS THAT IDENTIFIES THE DOMINANT FM"S DUE TO CHANGED REQUIREMENTS (USING JPL/DDP TOOL)

- USE SPARE FLIGHT HARDWARE

- BROAD SPECTRUM OF FAILURE MECHANISMS ACCELERATED DURING TEST

- TEST LIMITS SET BY A COMBINATION OF ANALYSIS AND A STEP STRESS TEST ON THE ENGINEERING MODEL UNIT

- DEGRADATION FROM TEST ESTABLISHED BY PERFORMING BONDWIRE PULL TESTING AFTER LIFE TEST COMPLETION
FM IDENTIFICATION/EVALUATION PROCESS

- USE DEFECT DETECTION & PREVENTION (DDP) TOOL
  
  - IDENTIFY SPECIFIC FAILURE MECHANISMS THAT CAN IMPACT THE NEW MISSION REQUIREMENTS
    - (MATRIX OF REQUIREMENTS VS. FAILURE MECHANISMS THAT CAN IMPACT THESE REQUIREMENTS)
  
  - IDENTIFY SPECIFIC TESTS/ANALYSES THAT COULD ASSESS THE RISK ASSOCIATED WITH IDENTIFIED FM’S
    - (MATRIX OF PREVENTIONS AND/OR DETECTION ACTIVITIES VS. FAILURE MECHANISMS THAT CAN BE PERFORMED)
  
  - YIELDS RESIDUAL RISK (BY SPECIFIC FAILURE MECHANISMS)

\[
\text{Residual Risk} = \text{How much I care} \times \text{How much I missed it}
\]
RESIDUAL RISK VS. PACT'S PERFORMED

BLUE = COLD PERFORMANCE, GREEN = FRACTURE DUE TO COLD, WHITE = MATERIAL FAILURE DUE TO SHEAR, TENSION OR COMPRESSION, RED = WIREBONE FATIGUE FAILURE, ORANGE = OTHER PART FAILURE

PACTs

Selected Estimate Fatigue Life to be Consumed i Mission
☑ Survive Launch and Flight to date
☐ Perform Life Test on Shunt Assy's
☑ Test the Fracture Toughness of BEO Header
☑ Measure the CTE of BEO (-150C to +100C)
☐ Perform Post Life Test Bondwire Pull Test
☐ Exposure Unit to New Cold Level With Margin

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EXPERIMENT DESIGN DETAILS

• DDP KEY RESULTS/DRIVING FAILURE MECHANISM
  • BONDWIRE FATIGUE (PARTICULARLY IN THE DRIVE Tx)
  • BeO DISK (HEADER) FRACTURE NEEDS TO BE VERIFIED
  • PACKAGING STRESS (BONDLINE SHEAR, DIE FRACTURE, ETC.)
  • SYSTEM PERFORMANCE @ COLD

• FAILURE MECHANISMS EXERCISED BY TEST
  • UNIT PERFORMANCE VS. TEMPERATURE,
  • WIREBOND FATIGUE LIFE,
  • PACKAGE STRESSES
  • POWER RELATED FAILURE MECHANISMS

• FAILURE MECHANISMS ACCELERATED IN TEST
  • WIREBOND FATIGUE LIFE,
    • CTE EFFECTS INTEGRATED OVER THE TEMPERATURE RANGE
  • PACKAGE STRAINS/StRESS ASSOCIATED WITH MATERIAL
    PROPERTY CHANGES OVER THE TEMPERATURE RANGE
EXPERIMENT DESIGN DETAILS

• TEST ARTICLES
  • TWO PSA FLIGHT SPARE UNITS & ONE ENGINEERING MODEL PSA
  • THREE FLIGHT SPARE DRIVEN Tx’S (FROM THE SAME LOT DATE CODE)
  • CONTROL DRIVE AND DRIVEN Tx’S USED (I.E. NOT LIFE TESTED)

• TEST LIMITS ESTABLISHED
  • STEP STRESS TEST ON THE ENGINEERING MODEL UNIT (-145C
    REACHED LIMIT OF CHAMBER +125C)

• DAMAGE ACCUMULATION VERIFICATION
  • DEGRADATION FROM TEST ESTABLISHED BY PERFORMING
    BONDWIRE PULL AFTER THERMAL CYCLING

• TEST CONDITIONS
  • PSA’S POWERED “ON”
  • SPARE TRANSISTORS NOT POWERED
  • 2,000 CYCLES FROM -125C TO +100 SELECTED
  • RAMP RATE ON THE ORDER OF 60C/MINUTE
# ACCELERATION FACTORS FOR PURE AL. WIREBOND FATIGUE

<table>
<thead>
<tr>
<th>Mission Phase</th>
<th>Cycles</th>
<th>TEMPERATURE RANGE</th>
<th>Strain</th>
<th>Range of PARIS POWER LAW EXPONENT for Aluminum</th>
<th>Equivalent Test Cycles (-125C TO 100C)</th>
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<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T2</td>
<td>dT</td>
<td>(Test/Env.) @ 1.5</td>
</tr>
<tr>
<td>Acceptance Test</td>
<td>18</td>
<td>90</td>
<td>-60</td>
<td>150</td>
<td>0.0029</td>
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<tr>
<td>T. V from</td>
<td>16</td>
<td>60</td>
<td>-55</td>
<td>115</td>
<td>0.0022</td>
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<td>Cruise</td>
<td>4700</td>
<td>47</td>
<td>47</td>
<td>47</td>
<td>0.0009</td>
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<td>Pre-Eclipse ANS Cycling (every 100 min from 9/11 to 1/2)</td>
<td>1627</td>
<td>10</td>
<td>-10</td>
<td>20</td>
<td>0.0004</td>
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<tr>
<td>Pre-Eclipse AB Drag Pass (P.0 to P.90)</td>
<td>90</td>
<td>10</td>
<td>-50</td>
<td>60</td>
<td>0.0012</td>
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<td>Phase 1 Eclipse Season ANS Cycling (Every 100 Min from 1/2 to 4/1)</td>
<td>1280</td>
<td>10</td>
<td>-10</td>
<td>20</td>
<td>0.0004</td>
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<td>Phase 1 Eclipse Season Eclipse &amp; AB Drag Pass (1/2 to 4/1)(60 min eclipse)(P.90 to P.300)</td>
<td>210</td>
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<td>-80</td>
<td>90</td>
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<td>Additional Eclipse Season</td>
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<td>100</td>
<td>0</td>
<td>0</td>
<td>0.0019</td>
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<td>Science ANS Cycling (4/1 to 11/1/98)(100 min spin)</td>
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<td>-10</td>
<td>20</td>
<td>0.0004</td>
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<tr>
<td>SIC (4/1 to 11/1/98)(6 hr orbit)(60 min Off-Point)</td>
<td>856</td>
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<td>-70</td>
<td>80</td>
<td>0.0015</td>
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<td>Eclipses during Science (4/1 to 11/1/98)(Avg 30 min)</td>
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<td>-50</td>
<td>60</td>
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<td>Mapping 1 Mars yr =687 days 40 Min Eclipses 12 orbits per day</td>
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<td>60</td>
<td>0.0012</td>
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<td>Relay phase 3 Earth years</td>
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<td>-50</td>
<td>60</td>
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<td><strong>Totals</strong></td>
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<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>0.0012</strong></td>
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# LIFE TEST RESULTS
## 2000 CYCLES (-125C to 100C)

<table>
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<tr>
<th>S/N</th>
<th>Pull Strength (grams)</th>
<th>Location of Failure Site (blank = failure in bond at die)</th>
<th>Thermal Cycle</th>
<th>Power Cycle</th>
<th>Control Sample</th>
<th>Type of Device</th>
<th>Notes</th>
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<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>71</td>
<td>216 371 360 337 511 425</td>
<td>Die Heel</td>
<td>Die Heel</td>
<td>Midspan</td>
<td>Die Heel</td>
<td>x</td>
<td>Driven</td>
</tr>
<tr>
<td>81</td>
<td>410 366 397 419 489 386</td>
<td>Die heel</td>
<td>Die Heel</td>
<td>Midspan</td>
<td>Die Heel</td>
<td>x</td>
<td>Driven</td>
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<tr>
<td>119</td>
<td>273 263 416 460 439 456</td>
<td>Die Heel</td>
<td>Die Heel</td>
<td>Midspan</td>
<td>Die Heel</td>
<td>x</td>
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<tr>
<td>80</td>
<td>18 21 318 200 0 NR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
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<tr>
<td>91</td>
<td>16 62 58 175 93 86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td>155</td>
<td>50 67 175 167 310 67</td>
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<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
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<tr>
<td>83</td>
<td>19 16 210 227 53 40</td>
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<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
</tr>
<tr>
<td>94</td>
<td>15 15 155 86 59 219</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
</tr>
<tr>
<td>121</td>
<td>91 165 153 * 158 23 NR</td>
<td>Post Heel</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
</tr>
<tr>
<td>143</td>
<td>78 207 282 289 145 331</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
</tr>
<tr>
<td>151</td>
<td>38 33 24 186 0 19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
</tr>
<tr>
<td>191</td>
<td>31 52 171 208 24 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
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<tr>
<td>193</td>
<td>33 81 65 113 19 81</td>
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<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
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<tr>
<td>194</td>
<td>73 57 107 153 137 105</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Driven</td>
</tr>
<tr>
<td>1</td>
<td>410 411 -- -- -- --</td>
<td>Die Heel</td>
<td>Die Heel</td>
<td>--</td>
<td>-- --</td>
<td>x</td>
<td>Drive 2</td>
</tr>
<tr>
<td>2</td>
<td>507 402 -- -- -- --</td>
<td>Die Heel</td>
<td>Die Heel</td>
<td>--</td>
<td>-- --</td>
<td>x</td>
<td>Drive 2</td>
</tr>
<tr>
<td>167</td>
<td>165 189 -- -- -- --</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Drive 2</td>
</tr>
</tbody>
</table>

Notes: NR = not recorded

1) Original FA performed at LM wiring convention not detailed beyond emitter side side and base.
2) These devices were from current manufacturer's lot due to lack of spares of original flight parts.
3) Failure classification according to Mil STD 883c, Notice 4, Paragraph 3.2.1a: Table entries translate to: Failure in bond = a-3; Die Heel = a-1; Midspan = a-2

Table 3. Summary of failure analysis results (pull strengths and failure location).
Figure 7. Top view of Transistors showing bondwire configurations. Bondwires are dead soft Aluminum 0.010 inches in Diameter on Aluminum metalization. Posts are Nickle. All are bonds ultrasonic. Bonds to die are orthodyne bonds while bonds to post are wedge bonds.
CLOSE UP OF A TYPICAL FAILURE SITE

Figure 8. View of bond pad #6 in S/N 094 showing area where bonding occurred.

Figure 9. Close up of region shown by middle arrow in Figure XXX.
TEST ACCELERATION FACTORS FOR AL. ON AL. WIREBONDS

• MISSION INVOLVES MANY CYCLES ~25,000
• TABLE INTEGRATES CTE EFFECTS OVER TEMP RANGE:
  – CTE NOT CONSTANT OVER TEMPERATURE
  – MISSION EVENTS EQUATED TO NUMBER OF TEST CYCLES
  – TOTAL MISSION EQUAL TO ABOUT 1,600 TO 2,200 CYCLES FROM -125 TO +100C
• RANGE FROM ABOUT:
  – 5 X TO 70 X
WIREBOND PULL TEST RESULTS

• TABLE SHOWS
  – BREAKING STRENGTH FOR 90 WIREBONDS
  – WIREBOND FAILURE SITE
  – TEST CONDITIONS/Tx TYPE
PULL STRENGTHS:

- VIRGIN WIREBONDS
  - TRADITIONALLY VARY GREATLY
  - HERE VARIATION RELATIVELY SMALL (MOST CASES ±10%)
  - MIL SPEC 883 SAYS OVER 80 g (BOL) IS ACCEPTABLE

- STRESSED WIREBONDS
  - ALL SIGNIFICANTLY DEGRADED
  - TWO HAD NO PULL STRENGTH
  - MANY LESS THAN 20% LIFE REMAINING (LAST 20% GOES VERY FAST)
FAILURE SITES & TEST STRESSES

• VIRGIN WIREBONDS FAILED MOSTLY IN THE HEEL ON THE DIE SIDE

• STRESSED WIREBONDS MOSTLY FAILED IN THE BOND METAL ON THE DIE SIDE

• FAILURE RESULTS ABOUT SAME FOR POWER + THERMALLY VS. JUST THERMAL CYCLED
  - SMALL % OF CAPABILITY USED
THERMAL CYCLING ENVIRONMENT

- MIL STANDARDS NOT NECESSARILY APPLICABLE FOR LIFE FOR PREFERRED NEW MISSION PLAN
- THE DESIGN "AS IS" CAN BE EXPECTED TO HAVE SUFFICIENT MOST LIKELY TO OCCUR
- THAT THE PM'S THE WAS TEST DESIGNED AROUND WERE THE

TEST RESULTS SHOWED

- MECHANISMS INCLUDED A VERIFICATION OF THE MOST LIKELY FAILURE
- MATERIALS PROPERTY DATA SIMPLIFIED MODELS AVAILABLE IN THE LITERATURE

TEST DESIGN PROCESS

- FAILURE MECHANISMS TO DESIGN THE TEST AROUND
- EFFECTIVE METHODOLOGY FOR IDENTIFYING SPECIFIC

DPP TOOL

CONCLUSIONS