Development of Ultra Low Temperature, Impact Resistant Lithium Battery for the Mars Microprobe

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ABSTRACT

The requirements of the power source for the Mars Microprobe, to be backpacked on the Mars 98 Spacecraft, are fairly demanding, with survivability to a shock of the order of 80,000 g combined with an operational requirement at -80°C. Development of a suitable power system, based on primary lithium-thionyl chloride is underway for the last eighteen months, together with Yardney Technical Products Inc., Pawcatuck, CT. The battery consists of 4 cells of 2 Ah capacity at 25°C, of which at least 25% would be available at -80°C, at a moderate rate of C/20. Each probe contains two batteries and two such probes will be deployed. The selected cell is designed around an approximate 1/2 "D" cells, with flat plate electrodes. Significant improvements to the conventional Li-SOCl₂ cell include: a) use of tetrachlorogallate salt instead of aluminate for improved low temperature performance and reduced voltage delay, b) optimization of the salt concentration, and c) modification of the cell design to develop shock resistance to 80,000 g. We report here results from our several electrical performance tests, mission simulation tests, microcalorimetry and AC impedance studies and Air gun tests. The cells have successfully gone through mission-enabling survivability and performance tests for the Mars Microprobe penetrator.
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Nov. 18, 1997

Yarbrough Technical Products

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and

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Harvey Frank, Frank Deliganis, Evan Davies,

Resistant Li Primary Battery for Mars Microprobe
Development of a Ultra-Low Temperature, Impact-
Mars Microprobe - Mission Description

NASA

Mars Microprobe - Mission Description

JPL
electromechanical drill incorporated in the forebody.

- Soil water content - spectrometer and
- Soil temperature data
- Atmospheric pressure data
- Acceleration data during entry and descent

SCIENCE OBJECTIVES
Figure I-7: Landed Configuration

Minimum Subsurface Temperature (°C)

Primary Lifetime = 72 Days
Penetration Depth > 0.3 m
Mass = 850 g

- Electronics
- Power
- Microcontroller
- Instrument
- Soil Collection Drill
- Soil Sample Chamber
- Thermal Sensors
- TTL H2O Experiment
- Flex Cable Connection
- Antenna

Primary Batteries
Descarted Accelerometer
Transceiver

Night

Depth (cm)

0
50
100
150
- Load profile attached
- Survive impact 200 m/sec
- 0.5 A-hr capacity at -80°C
- 2 A-hr capacity RT
- 2 year life
- 6 - 12 volts

Demonstrate flight like hardware that meets performance requirements

Mars Microprobe Battery Objective
Pan-cake (hat-plate) design in slice "D" cell.

- Conductivity.
- Lower salt concentrations (0.5 M vs. 1.0 M) improve electrolyte characteristics compared to tetraethylammonium.
- Lithium tetraethylaluminate gave improved discharge and voltage and discharge tests at -80°C.

**Li-SOCl₂** is the most suitable system from the polarization curves.

**BACKGROUND**
MARS MICROPROBE CELL
TOPICS

• Assessments
• Schedule

• Prior Issues
• Safety

• Installation and Wiring
• Inspections

• Special Topics
• Accelerated Storage

• Impact Testing
• Voltage Delay

• Battery Motor Tests
• Microcalorimetry and AC Impedance
NEW REQUIREMENTS FOR SURFACE OPS

- Transmit: 176 mA, 15 min, 80°C, TBD time
- H₂O heater: 605 mA, 20 min, 60°C, TBD time
- Drill: 88 mA, 10 min, 40°C, TBD time
- Science pulses: 33 mA, 60 to 80°C, each 1/2 hr
- Sleep mode: 1 mA, 60 to 80°C

Surface Operations for next 6 hrs
- 8 mA - 4 min, 13 mA - 4 min, 30 mA - 2 min
- Descent: first 10 min @ -40°C

REQUIRED LOADS (ORIGINALLY)

LOAD PROFILES
APPROACH

- Analyze data to make predictions.
- Measure heat from cells over a range of temperatures.
- Measure heat from cells using microcalorimetry, periodically during storage.
- Measure heat from cell using microcalorimetry.

OBJECTIVE

- Storage tests.
- Obtain 'acceleration factor' for elevated temperature.
- Determine effect of temperature on capacity losses.
- Predict capacity loss of cells for 2 year stand @ RT.
Exponential decay in corrosion rate during storage

Heat Output, micro W

Observed Cell Heat Output During Storage
Predicted based on extrapolation of experimental data.
Calculated based on a thermonutral voltage of 3.72 V.

Predicted Capacity Loss During Storage at RT.
Activation Energy: 1.64 Kcal/mole

Arrhenius Plot of Li Corrosion (Self Discharge)

\[ y = -1.4132x + 6.9185 \]
Lower storage temperature desired.

Capacity Loss in 2 years, Ah

Predicted Capacity Loss vs. Storage Temperature
APPROACH

- Detect signs of cell degradation during stand.
- Examine the (lithium) interfacial conditions that would impact stability.
- Examine the baseline impedance spectra of the cells.
- Establish baseline impedance spectra of the cells.
- Establish correlations, if any, with the life and voltage delay.

OBJECTIVE

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY
Film Resistance varies from cell to cell.

Impedance Spectra of Fresh Cells
Cell Resistance: 150-210 Ωm², consistent with the Ohm measurement.

Cell Number

Cell (Ohmic) Resistance

Resistance, Ohms
Film resistance varies from 5-40 Ohms.
Delay could pose problems at moderate currents @ -80 degrees C
40 to 60 degrees C
Delay appears significant but not excessive @ moderate currents @

(Experimental data on YRP 2 AH cells)

Voltage Delay
C for H2O EXPI @ 605 mA, and even higher new transmit to 1 A.

- No voltage depression from delay later in profile @ 60 degrees
- May incorporate short conditioning discharge prior to transmit @ 80 degrees
- Can meet initial transmit load but with little margin @ 80 degrees

• Voltage depression from delay is appreciable at moderate loads
  - Can meet early descent loads with adequate voltage @ temps to 60 degrees

• Moderate loads @ 40 to 60 degrees

• Voltage depression from delay is significant but not excessive at

CONCLUSIONS

VOLTAGE DELAY
OBJECTIVES

BATTERY - MOTOR TESTS
- DAS records steady state voltage and current
- Motor shall be frozen for stall
- Dynamo set for 1 inch-d to simulate stall current
- Scope injects by motor start and records transient voltage and current

DS2 Battery/Motor Test
-70 degrees C
Similar results from -30 to near 70 mA
Current quickly tapers to
Lasts only 25 ms
Min V near 10.0 V
Peak current near 1.4 A
Scope trace @ -60 degrees C

Battery Motor Tests
degrees C
Similar results from -30 to -70
Voltage near 7.7 V @ 390 mA
Start spike noted
4 min.
DAG trace @ 60 degrees C for

Sample - Stall Run @ 60 degrees C

BATTERY MOTOR TESTS
BATTERY TEMPERATURE, °C

STALL OF MOTOR @ -120 °C
BATTERY VOLTAGE AFTER 4 MIN

SENESt
Battery can operate drill and stall @ 60 degrees with margin.

Voltage level decreases with temp (7.7V @ 60 degrees C).
Voltage relatively stable for 4 min.
Currents near 400 mA.

Stall Characteristics

Voltage level decreases with temp (10V @ 70 degrees C, 4V @ 80 degrees C).
Voltage relatively stable for at least 10 min.
Currents near 70mA.

Run Characteristics

Minimum voltage decreases with temp (8V @ 70 degrees C, 4V @ 80 degrees C).
Current near 1 A for 25 ms.

Starting Characteristics

Summary/Conclusion

Battery Motor Tests
mission profile and temp.

• Retrieve assembly and conduct discharge tests in accord with
• Fire assembly into target with airgun
• Install cells in probe assemblies

APPROACH

- Deliver required electrical loads at minimum temperatures
- Withstand 200 m/sec impact shock

OBJECTIVE

IMPACT TESTING
Two cell configurations in probe

Electrode stacks + electrolyte same for old and new types
- New: GTM + Thicker cover with pin in center & fill tube on side
- Old: GTM + Cover with fill port in center & terminal

Two cell types

TEST ITEMS

IMPACT TESTING
<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>DATE</th>
<th>CELL TYPE</th>
<th>NO CELLS</th>
<th>PROBE TYPE</th>
<th>AOA</th>
<th>HIGHLIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>10/29/97</td>
<td>NEW</td>
<td>7</td>
<td>11</td>
<td>11</td>
<td>No cracks, no leaks, 7 functioned, both got GTM cracks and leaks, 1 bulged, 1 functioned</td>
</tr>
<tr>
<td>50</td>
<td>8/28/97</td>
<td>NEW</td>
<td>8</td>
<td>11</td>
<td>11</td>
<td>All got GTM cracks and leaks, 1 opened, 7 functioned</td>
</tr>
<tr>
<td>42</td>
<td>5/29/97</td>
<td>OLD</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>Both got GTM cracks and leaks, both functioned</td>
</tr>
<tr>
<td>38</td>
<td>4/4/97</td>
<td>OLD</td>
<td>4</td>
<td>11</td>
<td>NA</td>
<td>3 functioned</td>
</tr>
<tr>
<td>36</td>
<td>3/13/97</td>
<td>OLD</td>
<td>4</td>
<td>21</td>
<td></td>
<td>All got GTM cracks and leaks, both functioned</td>
</tr>
</tbody>
</table>
"Open" due to faulty pin welded
- Cells survived and functioned (with leaks)
- Old GTM Seal Assembly inadequate
- One layer configuration appears best

Significance

Remaining 7 cells delivered good output @ -80°C

1 cell developed "open" condition

But all cells had small cracks & slow leaks in GTM

No venting

8 cells, old design, 1 layer confi

OVERVIEW

AIRGUN TEST # 42
(opened)

- 0.82
- 0.85
- 0.80
- 0.87
- 0.64
- 0.36
- 0.75
- 0.75
- 0.75

Cell

Discharge Load Tests @ - 80 degrees C

- 10 ohm
- 61 ohm

Best estimates below

Descent Load Tests @ - 40 degrees C

Discharge Test Results

Airgun Test #42
Must investigate cause for bad cell in 3 cell batt

Extrernal wiring mods appear to have eliminated shorts

New seal design again withstand shock

**SIGNIFICANCE**

- Operated on constant load of 80 C @ 10 W - 60 C
- 1 bad cell in 3 cell batt limited output but this batt
- High power transmit of 10 W
- 4 cell batt delivered good output on profile, also delivered
- No leaks and no venting
- Improved extrernal wiring
- 7 cells as 4 and 3 cell batts, new seal design, 1 layer confing

**OVERVIEW**

AIRGUN TEST # 53
MISSION PROFILE TEST

AIRGUN TEST # 53

T = -80°C

T = -60°C
Also examine trends in voltage delay.

Compare actual with projected capacitances.

Periodically remove and test cells.

Store additional cells at elevated temperature.

Store some cells at ambient temperature.

APPROACH

Support microradiometric projections.

Project performance after 2 years storage.

OBJECTIVE

ACCELERATED STORAGE
No measurable loss in capacity at 50 degrees C

1 month @ 50 degrees C

1 month @ RT

CAPACITY TESTS

ACCELERATED STORAGE
Ran motor > 4 min @ temp > -60 degrees C
Sustain 1 A surge stall current
Run motor > 10 min @ temp > -60 degrees C
Sustain 1 A surge starting current

Battery can successfully operate drill motor
Accelerated tests consistent with projections.
Improved retention at lower temps
78-93% capacity retention after 2 yrs @ RT
 Favorable Project for meeting 2 year shelf life

ASSESSMENT
Successful repeat run would help ensure meeting goal.

Must determine cause for one "low" cell in Airgun #53

met profile and 10 W

Several cells delivered good post impact part and a battery externa wiring mods eliminated external shorting

New GTM-cover design eliminated cracking and leaks and

IMPACT SURVIVABILITY

Temperatures - 80 degrees C

Limits maximum initial load especially at very low initial loads @ -40 to -60 degrees C

Effects present but not excessive for planned moderate

VOLTAGE DELAY

ASSESSMENT 2
Bluestar under Air Force contract. Air Force Research Laboratory. The cells were fabricated by Aeronautics and Space Administration and in collaboration with the California Institute of Technology under contract with National Laboratory.

This work was carried out at the Jet Propulsion Laboratory.

Acknowledgement

NASA