Thermal Vacuum Testing of a Multi-Evaporator Miniature Loop Heat Pipe

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Outline

- Introduction/Background
- Test Article
- Thermal Vacuum Test Set-up
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- Summary and Conclusion
Under NASA’s New Millennium Program Space Technology 8 Project, four experiments are being developed for future small system applications requiring low mass, low power, and compactness.

GSFC is responsible for developing the Thermal Loop experiment, which is an advanced thermal control system consisting of a miniature loop heat pipe (MLHP) with multiple evaporators and condensers.

The objective is to validate the operation of an MLHP, including reliable start-ups, steady operation, heat load sharing, and tight temperature control over the range of 273K to 308K.

An MLHP Breadboard has been built and tested for 1200 hours under the laboratory environment and 500 hours in a thermal vacuum chamber.

Results of the TV tests are presented here.
LHP Basics

- No external pumping power and no moving parts
- Passive and self-regulating
- Operating temperature can be controlled at the desired set point
- State-of-the-art
  - Single evaporator
  - 1 inch (25.4mm) wick
  - Heating the CC only, no active cooling
Thermal Loop Concept Description

- Miniature Loop Heat Pipe
  - Two parallel evaporators
  - Two parallel condensers
  - Compensation chambers (CC)
    - Fluid reservoir
  - Flow Regulator
    - Prevents vapor blow through when only one condenser is fully utilized
  - Working Fluid
    - Anhydrous ammonia

- Instrument Simulators
  - Simulate instruments or electronic box

- Thermoelectric Converters (TECs)
  - Maintain CC saturation temperature
  - Variable set point control

- Coupling Blocks
  - Reduce control heater power requirements by transferring heat from vapor to return liquid
Pictures of MLHP Breadboard 2

Overall View

Close View of Evaporator/CC Section
ST8 Breadboard 2 – TC Locations
Test Setup and Instrumentation

- Each evaporator has a 400-gram aluminum mass attached.
- A cartridge heater was inserted into each thermal mass to provide 1W to 150W of heat load.
- A cooling block was attached to each thermal mass to provide a heat sink for heat load sharing tests. The coolant temperature and flow rate were varied during the test.
- A thermoelectric converter (TEC) was attached to each CC. The other side of the TEC was connected to the evaporator through a copper strap.
- Each TEC was connected to a separate bi-polar power supply.
- More than 100 type T thermocouples were used.
- Data acquisition system
  - Two dataloggers
  - Two PCs
  - Collect, display, and store data every second.
- Labview software was used for command and control of test conditions.
Problem Encountered During Testing

- A problem with the test set-up led to sporadic data drops.
  - Each time this happened, all temperatures read 282K for a single data scan.
  - The TECs responded to this erroneous reading, changing the saturation temperature.
  - As a result, the CC temperature fluctuated about 1K for a few minutes until stable temperatures were reestablished.

- In spite of this problem, the TECs demonstrated their abilities to bring the CC temperature quickly to the desired set point temperature.
Tests Performed

- Start-up
- Operating Temperature Control
  - TECs and electrical heaters
  - Power cycle
  - Sink temperature cycle
  - CC temperature change
- Heat Load Sharing
- Flow Regulator Function
- TEC Power Savings
  - Effects of Coupling Blocks on CC Control Heat Power
- Demonstrated more than 500 hours of LHP operation under a wide range of operating conditions in a thermal vacuum environment.
Start-up Tests

- 51 start-up tests were conducted. All were successful.
  - Start-up was indicated by the rise of the vapor line temperature and the drop of the liquid line temperature.

- CC temperature: 0, 1 or both CCs were controlled between 258K and 308K

- A heat load of 5W to 50W was applied to one evaporator, independent of the heat load to the other evaporator, i.e. even and uneven heat loads

- Temperatures of the two condenser sinks varied between 203K and 273K, independent of each other
Start-up
308K/308K, 0W/50W

- With 50W to E2, Mass2 and E2 temperature reached the set point quickly.
- E1 began to share heat after loop started.
Start-up
293K/293K, 0W/5W

- 2.5K superheat on E2 at start-up
- E1 shared heat after loop started.
Start-up
No control/293K, 50W/5W

- E1 was flooded prior to start-up.
- E1 reached set point temperature first and started the loop with 7K superheat.

![Graph showing temperature and power over time with various lines and markers for E1, E2, CC1, CC2, Vap Line, Liq Line, and E1/E2 powers.](image-url)
Saturation Temperature Control

- The loop operating temperature could be controlled by controlling the temperature of one or both CCs.

- The loop operating temperature could be controlled within ±0.5K using TECs or electrical heaters.

- The loop operating temperature could be changed while the loop was operating.

- Using TECs, the loop operating temperature could be controlled below the ambient temperature and below the loop’s natural operating temperature.
Power Cycle

- CC1/CC2 = 293K/293K, C1/C2 sink = 173K/173K
- E1/E2 power = 75W/0W, 50W/25W, 25W/50W, 0W/75W, 5W/50W, 50W/5W
- The loop operating temperature was maintained within ±0.5K of the 298K set point temperature.
CC Set Point Change

- C1/C2 sink = 223K/223K. E1/E2 power = 10W/10W.
- TECs enabled CC1/CC2 to control the loop saturation temperature below its natural operating temperature.
Heat Load Sharing

- CC1/CC2 = 303K/NC, E2 power = 50W constant, C1/C2 sink = 203K/243K
- E1 coolant flow rate = 0.15 gpm
- E1 coolant temperature = 283K/288K/293K/298K/303K/308K
- As coolant temperature reached 303K and 308K, E1 received heat from the coolant and was in its normal operation (shared negative heat)
Flow Regulator Test

- E1/E2 power = 30W/10W constant. CC1/CC2 = 293K/293K
- Both sides of the flow regulator worked properly to stop vapor.
TEC Power Savings Test

- Thermal Loop design incorporates coupling blocks and TECS to reduce control heater power requirements. Test were conducted using electrical heaters and TECs.
  - Quantify amount of power savings

- Power to E1/E2: 10W/10W, 20W/10W, 30W/10W, 40W/10W, 50W/10W, 60W/10W, 70W/10W.

- CC1/CC2 set point: 308K(EH)/308K(TEC), 308K(TEC)/308K(TEC)

- Number of coupling blocks: 0, 2 and 3.
  - Affects temperature of returning liquid
  - Affects control heater power requirement
• TECs reduced control heater power by more than 60% compared to electrical heaters.
• Coupling blocks were also effective in reducing the control heater power.
• Combination of coupling blocks and TECs yielded significant power savings.
• Ambient tests under various sink temperatures and 0, 2, 3, 4 blocks showed similar power savings.
Summary

- The MLHP demonstrated more than 500 hours of operation under a wide range of operating conditions in a thermal vacuum chamber.

- One hundred percent success rate of start-up: turn-key start-up with TECs.
  - CC temperature: 0, 1 or both CCs were controlled between 258K and 308K
  - Heat load between 5W and 50W to either one evaporator independently

- Operation
  - The LHP operating temperature was controlled within ±0.5K of the desired set point
  - Stable LHP operation at all times over the full range of heat loads and sink temperatures
  - Demonstrated heat load sharing between the two evaporators

- TEC for temperature control
  - Provided both heating and cooling
  - The loop operated below natural operating temperature
  - Saved control heater power by > 50% compared to electric heaters
Protoflight MLHP for TRL 6 and TRL 7 Validation
MLHP Module Concept for TRL 7 Validation
(view from Spacecraft)
Thermal Loop Capabilities

- Turn-key start-up using TECs

- Fine temperature control at any temperature between 273K and 308K

- Control temperature can be varied while operating.

- Thermal bus for multiple instruments or heat dissipating locations
  - Any power distribution between two heat sources up to the maximum total load, including negative loads (heat load sharing) for one load.

- 100W+ heat transport limit

- Heat dissipation to radiators exposed to different thermal environments.
  - Will continue to operate as long as one radiator can dissipate entire load, even if other radiator has a net heat gain.
QUESTIONS?