Sorption Coolers Using A Continuous Cycle to Produce 20 K for the Planck Flight Mission


Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
Outline

- Introduction to Sorption Coolers
  - For Planck Flight Mission

- Key Cooler Requirements

- Basic Operating Principle

- Key Features of Sorption Coolers
  - That Make Them Attractive for Future Space Missions

- Maturity of Sorption Coolers & Status of Planck Flight Coolers

- Key Processes for Cooler Qualification

- Engineering Breadboard Cooler Test

- Conclusions
Planck 19K/22.5K Sorption Cryocoolers

Planck S/C

Cold End

Compressor Element

Compressor Assembly
Overall Cooler (TMU) Configuration

PLANK SORPTION COOLER

Using metal hydrides to provide 1 Watt of vibration free cooling at 20K

Compressor Elements

NASA
Key Performance Requirements
Cooler Thermo-Mechanical Unit, TMU (excl. electronics)

- Provide ~ 1W Total Heat lift at instrument interfaces
  - LFI @ < 22.5 K [80% of Total Cooling]
  - HFI @ < 19 K [20% of Total Cooling]
  - With ≤ 60 K pre-cooling temperature of coldest V-Groove
- Temperature stability* (over TMU oper. period, ~4000 s):
  - ≤ 450 mK, max. to min. at HFI Interface
  - ≤ 100 mK, max. to min. at HFI Interface
- TMU Input Power Consumption < 470 W (EOL)
- Operational Lifetime: 2 years
  - 18 months flight; 6 months total ground tests (JPL+Europe)
- Storage Life: 6 years
- Two completely independent coolers (TMU+Electronics)
  - provides 100% redundancy
- Mass and Volume (Each Cooler):
  - Total mass ≤ 53.3 kg
  - Total Compressor Volume < 1 m X 0.75 m X 0.25 m
Basic Operating Principle

Radiator

Heat Switch

High pressure hydrogen

Sorbent Bed

Pre-Cooler

J-T

Liquid refrigerant

Heat from sensors

Desorption

High T

D

C

Low T

A

B

Absorption

H/Sorbent Mass Ratio

Pressure
Simplified Schematic of Sorption Cooler
Key Features of Sorption Cooler

- Very Attractive for Future Space Missions

- No Moving Parts
  - Vibration Free

- Pressurization & Evacuation by Simple Heating & Cooling
  - Robust & Long Life
  - Reliable

- Expansion by Simple J-T Orifice
  - Cold End Can Be Remotely Located From Warm End
  - Excellent Flexibility of Integration of Cold End With Instruments Away From Warm Spacecraft
Maturity of Sorption Coolers & Status of Planck Flight Coolers

- JPL Has Been a Pioneer in the Development and Application of Sorption Coolers for Space Missions
- A Proof of Principle Cooler Was Developed, Built and Tested in Xxx
- Following That a Batch Mode Sorption Cooler, BETSCE, Was Tested in Space Aboard the Space Shuttle in Xxx
  - This Cooler Produced Solid Hydrogen at 9.1 K
- The Two Planck Sorption Coolers Are the First Continuous Cycle Sorption Coolers to Be Used for a Space Mission
- Planck Launches in 2007
- Delivery of Two Flight Coolers in Early 2005
- Prior to Flight Cooler Delivery, Cryogenic Qual. Model of Piping & Cold End PACE) will be delivered in Early 2004
  - For Vibration & Cryogenic Testing
  - Coupled to V-Grooves & Instrument Interfaces
  - PACE CQM cold end assembled
- Currently 1st Flight Compressor Assembly Almost Assembled
- Will be vibration tested at JPL soon after assembly with S/C radiator simulator
Key Processes for Cooler Qualification

- Component, Subsystem & System Level Qualification
- Component
  - Hydride BOL/EOL performance by Aging and Cycling in Flight Environ.
  - All critical components underwent qualification testing
    - e.g., Check Valves, Heaters, Filters, Valves, J-T expander, Gas-Gap Actuators (GGA), Heaters, Pressure Transducers, Temp. sensors, Etc.
    - Mechanical, Functional, Cycling, Thermal, Vibration
  - Pressurized Components underwent Proof & Burst Tests
- Subsystem
  - Three Compressor Elements (CE) Identical to Flight Design Life-cycled for 5,000 Cycles each
  - Prototype GGAs Cycled to 24,000 Cycles
  - Pathfinder CEs using Flight Spares was cycled to Demonstrate GGA On-Off Swicthing Performance
- System
  - Engineering Bread Board Cooler Built, Assembled & Tested
EBB Cooler

- EBB Cooler Validated Planck Flight Cooler Design
- Operated for 4,300 Hours (Flight Cooler Lifetime = 16,000 hours)
- Validated Interactions Between Components & Subassemblies, Incl. Cooler Electronics
- In General, Excellent Agreement Arrived at Between Predicted and Observed EBB Cooler Performance
- Difference Between Expectations & Observations Used to Modify Design of Flight Cooler
  - E.g., Observed Temperature Fluctuations > Expected
  - Flight Design Changed to Implement Thermal Stabilization @ Cold-End
- Operation of EBB Cooler Led to Important Operational Lessons for Flight System (implemented In Flight System)
  - Recharge H2 with Fresh Charge after few weeks of operation to remove residual contaminants
  - Developed Robust & Fast Operational (startup/restart) Algorithms
  - Developed Rapid J-T Defrost and Recovery Algorithm
- Validated Design of Test Facility to Be Used for Flight Coolers
EBB Cooler

Figure C. Photograph of 108K and 55K pre-cooler (PC 2, PC 3a, PC 3b)

Figure B. Photograph of EBB compressor

Figure D. Photograph of pathfinder flight-like cold end

Figure E. Photograph of path, EBB section
Conclusions

- Extremely successful testing of the EBB cooler demonstrated the viability of sorption coolers designed for space missions.
- Excellent agreement between predictions for the EBB cooler performance and the test results validated the flight cooler design.
- All important lessons learned from EBB testing were incorporated in the design, assembly and testing of the flight coolers.
- Excellent progress has been made in the construction of the coolers that will be delivered to ESA for the Planck mission.
- Based on the approach taken to design, build and test the flight coolers and the progress made until now, all indications are the Planck sorption coolers will operate successfully in flight and meet their requirements.
- Success of the Planck coolers will pave the way for a more widespread usage of such coolers for space missions.