Thermal Modeling Issues Concerning the Mechanically Pumped Two-Phase CO₂ Cooling for the AMS-2 Tracker

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• Numerical modeling and design issues
**Alpha Magnetic Spectrometer**

- (x,y,z) particle trajectories determined by momentum and charge sign
  - Curvature radius: momentum
  - Curvature direction: charge sign
- Energy loss in each silicon plane yields charge magnitude
AMS Silicon tracker thermal requirements

Silicon wafer thermal requirements:
- **Operating temperature:** -10 °C / +25 °C
- **Survival temperature:** -20 °C / +40 °C
- **Temperature stability:** 3 °C per orbit
- **Maximum accepted gradient between any silicon:** 10.0 °C
- **Dissipated heat:** 2.0 Watt EOL

Hybrid circuit thermal requirements:
- **Operating temperature:** -10 °C / +40 °C
- **Survival temperature:** -20 °C / +60 °C
- **Dissipated heat:** 192 Watt total, 1 Watt per hybrid pair

General requirements
- Limited mass (<70 - 80 kgs)
- Limited power (< 80 W)

Heat dissipation in the AMS-Tracker

The tracker front-end electronics (hybrid) are shown as the green boxes along the periphery of each layer. Each hybrid produces 1 Watt of heat.
• 2 Identical completely separated loops (1 for redundancy)
• 2 serial evaporators in parallel per loop
• 2 parallel condensers controlled per loop controlled by a 3-way valve.
• Pressure controlled with a thermal control reservoir
• Thermal control using standard AMS control module
• Critical components in redundant configuration (pump, valves)
• Most fluid components in 2 dedicated TTCS boxes on the support structure at wake side
• RAM and WAKE heat pipe radiator
• All hardware is placed in debris-safe areas; a specific debris shield is added when needed
**Tracker (component) design**

- 2 parallel evaporator branches
- 2 parallel condenser branches, 2 radiators
- pump assembly

**Evaporator**

TTCS evaporator connection to inner thermal bars

Complete thermal system in side the tracker (Thermal bars+ evaporators)

Inner planes evaporator
Radiators

Plumbing schematic
Experiments

• Feasibility test set-up @ NIKHEF
• Control BBM @ NLR
• Real size BBM @ NLR operational since early this year
  – First tests are promising
  – Full test campaign expected to start in fall 200

Breadboard

LN₂ cooling
wake condenser
ram condenser
accumulator
evaporator feed line (SS)
evaporator line (black)
pump
Numerical modeling

- Modeling information flows
- Component modeling fixed with loop temperature
- Simulation cases for design optimization
  - Radiator size, mass and shape
  - Heat pipe puncture
  - Preheating
Temperature gradients of the inner thermal bar (Tc0=0°C)

7.0 °C / 9.4 °C
10.5 °C / 11.5 °C
12.6 °C / 16.1 °C

Measurement / Simulation
Temperature gradients of the inner thermal bar (Tc0=0°C)

Outer plane thermal bar thermal simulation
**Loop model**

- Temperatures, links S/S & environment

**TTCS loop, typical result**

- Liquid line
- Vapour line
- Cond. RAM
- Cond. Wake
- Wake
- RAM

**β=0**

MPA

Flat radiator
**Radiator size:**
**Heat pipe failure**

![Graph showing temperature vs. time with lines for T1 and T1, hpf.]

Reduction of effective radiator area

**Preheating**

![Graph showing preheating power vs. time.]

- $Q_{average} = 60 \text{ W} \times 2 \text{ branches}$
- $Q_{max} = 114 \text{ W} \times 2 \text{ branches}$
- $Q_{average} = 14 \text{ W} \times 2 \text{ branches}$
- $Q_{max} = 32 \text{ W} \times 2 \text{ branches}$

11 W, due to setpoint
Conclusions

- Feasibility of TTCS supported by numerical model
- Several design choices based on and supported by thermal modeling
- Proven to be an important tool in engineering discussions with AMS experimenters