Customer specific demands on cryocoolers

from a design with high potential to a successful range of products
Contents of the presentation

Conceptual design

Reliability and lifetime
- analysis of failure modes
- reproducibility in fabrication

Cooler induced disturbances
- EMI
- cooler induced vibrations

Mechanical environment
- random / sine vibration
- shock

Economic aspects
- different applications - different constraints

Conceptual Design

Non-contact options studied and evaluated since 1997
- Gas bearings
- Folded leafsprings
- Flexure bearings

Requirements on flexures:
- High ratio radial / axial stiffness
- Sufficient margin in maximum stress
- Correct stress distribution over flexure
- Slow non-linear decrease of radial stiffness
- Sufficient axial stiffness to avoid mid position control (e.g. no launch lock)
- Sufficient radial stiffness to operate in ‘violent’ environments (high vibration, high g-forces)
Moving magnet design:
- two rings of radial magnetised permanent magnets (connected to the moving piston)
- two coils wound outside of pressure vessel

Important advantages:
- no gas contamination due to coil
- no glass feed-through required
- no moving coils, so no flying leads required

Main disadvantages:
- slightly higher (low-frequency) EMI due to moving magnet
- slightly less efficient (less magnet material)

## Reliability

Comparison of failure modes

<table>
<thead>
<tr>
<th>FAILURE MECHANISM</th>
<th>conventional space coolers</th>
<th>Thales LSF coolers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pulse Tube w/ back to back compressor</td>
<td>Stirling + balancer w/ back to back compressor</td>
</tr>
<tr>
<td>Excessive Internal Cooler Contamination</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Hermetic Seal or Feedthrough Leak</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>Comp. Flexure Breakage (fatigue)</td>
<td>0.1</td>
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<tr>
<td>Comp. Motor Wiring Isolation Breakdown</td>
<td>1</td>
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<tr>
<td>Comp. Piston Alignment Failure</td>
<td>0.2</td>
<td>0.2</td>
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<tr>
<td>Comp. Piston Blowby due to Seal Wear</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Comp. Piston Position Sensor Failure</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Expander Structural Failure (launch)</td>
<td>0.2</td>
<td>0.2</td>
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<tr>
<td>Expander Blowby (wear)</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Expander Motor Wiring Isolation Breakdown</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Expander Spindle Alignment Failure</td>
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<td>0.2</td>
</tr>
<tr>
<td>Expander / Balancer Position Sensor Failure</td>
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</tr>
</tbody>
</table>

Total failure probability (%)
- conventional space coolers: 7.5%
- Thales LSF coolers: 13.7%

*JPL, ICC 2000
Flexibility towards our customers
- fabrication of a variety of small series
- high quality required from very 1st delivery

Suproc fabrication database
- tracking and tracing of parts
- all measured data stored and available throughout plant
- analysis of measurement results

Intralink / Productview configuration management
- easier to manage large number of different configurations

HTML based manufacturing instructions
- easily accessed via SUPROC
- always the latest information available for everyone

Tooling optimised for reproducible output
- regenerator stacking machine (different regenerator diameters)
- hydrostatic lathe (reproducible \( \mu m \) accuracy)
- high vacuum brazing
- laserwelding

Check and double-check
- frequent calibration and verification of machine output
- visual inspections at all critical stages
- performance checks at several stages in production
- internal auditing : check the inspectors
Presently 10 LSF coolers running in lifetime tests; accumulated hrs > 160,000 hrs
4 coolers are over 22,000 hrs, 5 are over 11,000 hrs.

**Cooler Induced Disturbances**

*Electromagnetic Interference*

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>[dBμT at 7 cm]</th>
<th>[μT at 20 cm]</th>
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RE01 (MIL-STD-461 C)  INDUSTRIAL  SQUID ????
Customer specific demands on cryocoolers

Mechanical Vibration

Cooler induced vibrations

- COMPRRESSOR
- COMPRRESSOR + PULSE TUBE + VIBR CONTROL

Mechanical Environment

Random vibration environments

- DEFAULT COOLER SPEC
- AIRCRAFT 1
- AIRCRAFT 2
- AIRCRAFT 3
- SIN/EI
Mechanical Environment

Sine vibration comparison

- **DEFAULT COOLER SPEC**
- **SPACE 1**
- **RESONANCE 65-110 Hz (passed)**

Mechanical Environment

Shocks (SRS)

- **AIRCRAFT 1**
- **AIRCRAFT 2**
- **100g 11ms 3x per axis**
- **40g 6ms 2000x per axis**

foto valproef
Economical Aspects

<table>
<thead>
<tr>
<th>Application Fields</th>
<th>Technology</th>
<th>Price</th>
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<tbody>
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<td>SPACE</td>
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<tr>
<td></td>
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<tr>
<td></td>
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<td>price</td>
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</tbody>
</table>

Flexibility in design

Sample of deliveries March 2003