A linear Stirling cooler for extreme ambient temperatures

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Background

A customer active in the petrochemical industry is developing an imaging tool to inspect inside oil wells

Oil reserves near the earth surface become depleted

- Maintenance on existing wells is needed
- New wells at increasingly larger depths

For imaging equipment in ‘Wireline’ tool, an active cooling solution was needed

- Ambient temperature: 150 °C
- Cooling power: 24 W
- Tip temperature: 223 K
Cooler trade-off and thermodynamics

What to use: Stirling or Pulse-tube

- Ideal efficiency versus $T_{\text{amb}}$: Stirling much higher
- Stirling cooler typically smaller per watt of cooling power
- Pulse-tube is more reliable, but this high reliability not required in this application

Thus: **Stirling cooler for this application**

Theoretical efficiency versus tip temperature, $T_{\text{amb}} = 150^\circ C$

Stirling: $COP_{\text{max}} = COP_{\text{carnot}} = T_i / (T_h - T_i)$

Pulse-tube: $COP_{\text{max}} = T_i / T_h$
Cooler design

- **Moving magnet compressor**

- **Pneumatically driven Stirling Cold finger**
  - Cold finger dimensions close to existing 20 mm LSF9340 cold finger
  - Optimized regenerator and displacer tuning
Design challenges

High ambient temperature poses several challenges in the design, such as

➤ Materials strength
  - Yield strength, ultimate strength
  - Fatigue

➤ Materials properties
  - Copper resistivity
  - Curie temperature of magnets
Yield strength of austenitic stainless steels

Austenitic stainless steels

- Strength decreases to about 70% of room-temperature value
- Separate weld qualification performed at high temperature
Fatigue limit of spring steels

- Standard spring steel not suitable for high temperature use
  - New material selected. Fatigue limit experimentally verified
Performance – Qualification Models

Cooling power versus tip temperature

- 175 W input power, 150 °C ambient temperature
Performance – Qualification models

Cooling power versus input power

- 223 K tip temperature, different ambient temperatures
Performance – Thermal management of coils

Coil temperature versus input power

Different ambient temperatures

![Graph showing coil temperature versus input power for different ambient temperatures (150°C, 125°C, 100°C, 75°C).]
In total, 20 coolers built to date

- ATR measurement: cooling power at 223 K tip and 150 °C ambient for different input powers
Conclusions

- A linear Stirling cooler for extreme ambient temperatures is successfully designed, built and tested.
- Main challenges in the impact of the high temperature on materials properties.
- Cooler successfully tested and qualified for performance and environmental conditions.
- Up to now, 20 coolers built with consistent performance.