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SPIE-DCS 2018

ROBUST LINEAR STIRLING COOLERS FOR SENSING IN EXTREME ENVIRONMENTAL CONDITIONS

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Outline

Cryocoolers for extreme ambient temperatures

- Requirements and design choices
- Material strength
- Magnet selection
- Performances

Cryocoolers for extreme mechanical conditions

- Classical approach for testing
- Proposed integral approach
- Step-stress testing
- Life time testing

Cryocoolers for extreme ambient temperature conditions

Requirements:

- 150 C ambient temperature
- Cooling to (only) 220 K
- Limited duty cycle

Design choices?

- Newly designed close contact seal, moving magnet compressor
- Pneumatic cold finger (based on LSF9340)

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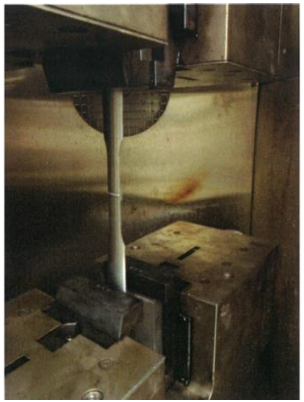
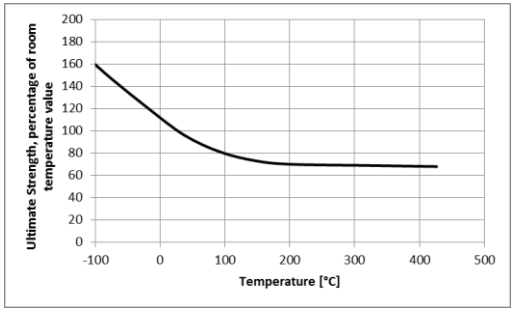
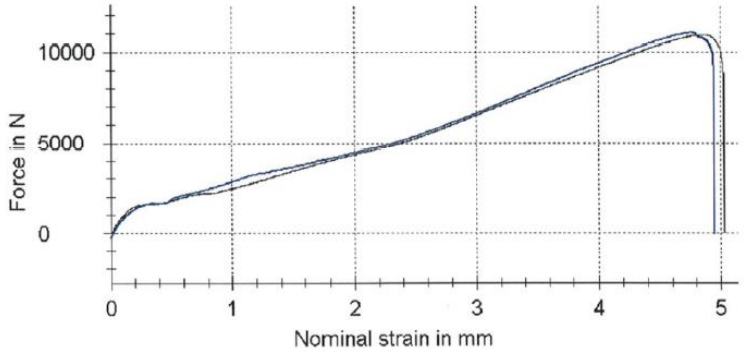
High temperature: Strength considerations

Tensile strength reduced:

- Lower material strength taken into account in FEA
- High temperature tests for weld strength







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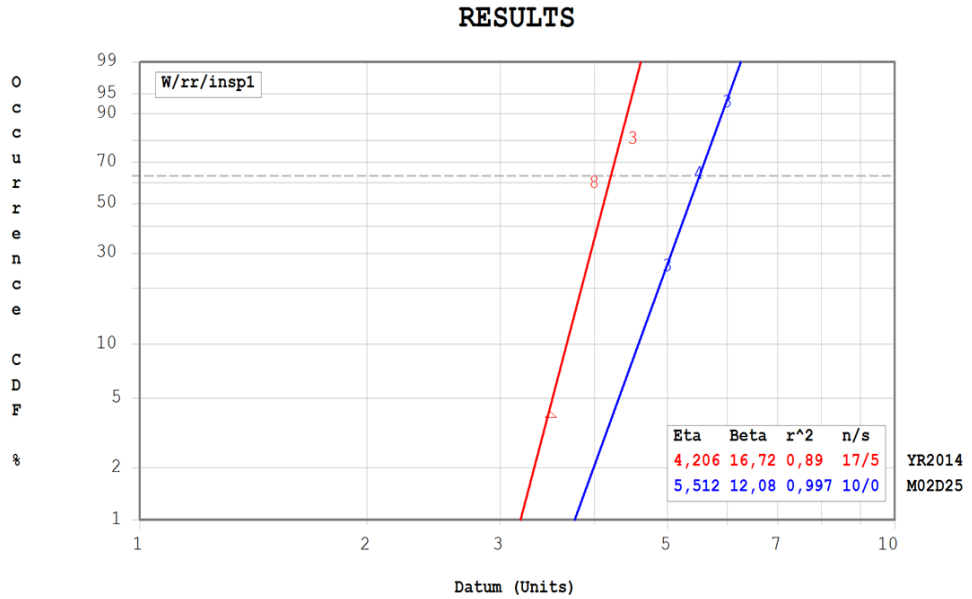
High temperature: Fatigue life

Compressor springs tested to >10^7 cycles

- Two batches tested: untreated and heat-treated spring material
- Amplitude of cycles increased until spring breakage
- Weibull analysis performed

Conclusion:

- Heat-treated material selected for product



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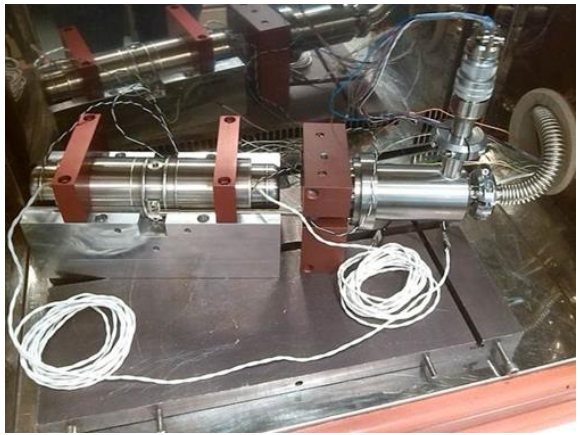
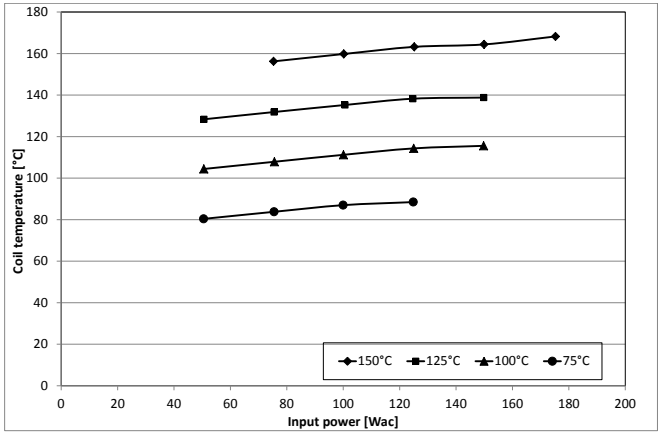
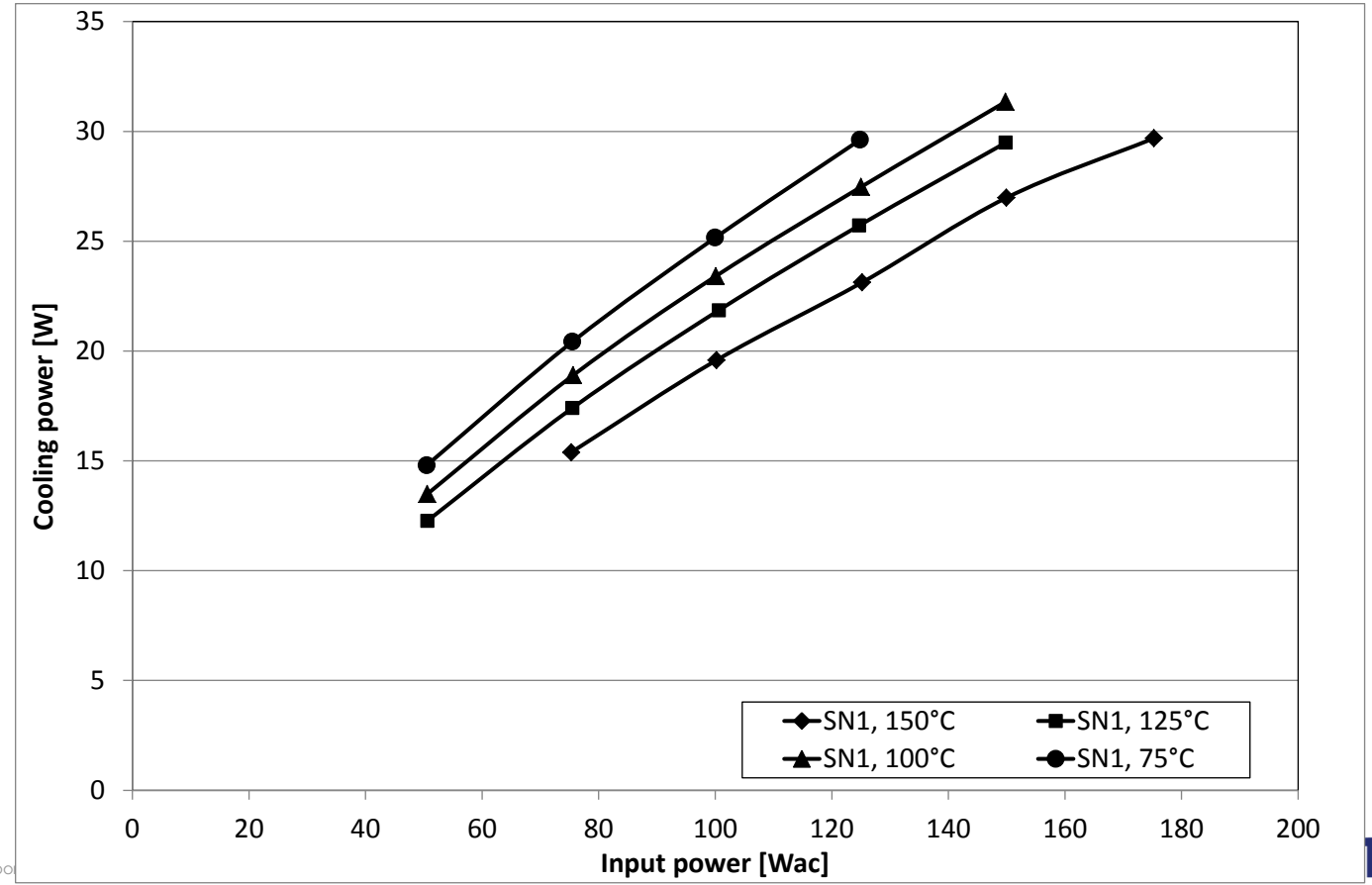
Magnet circuit under high ambient temperatures

- Magnet selection based on margin vs demagnetization (temperature/working point)
- Coil resistance dependent on temperature -> tests performed to ensure no thermal runaway occurs

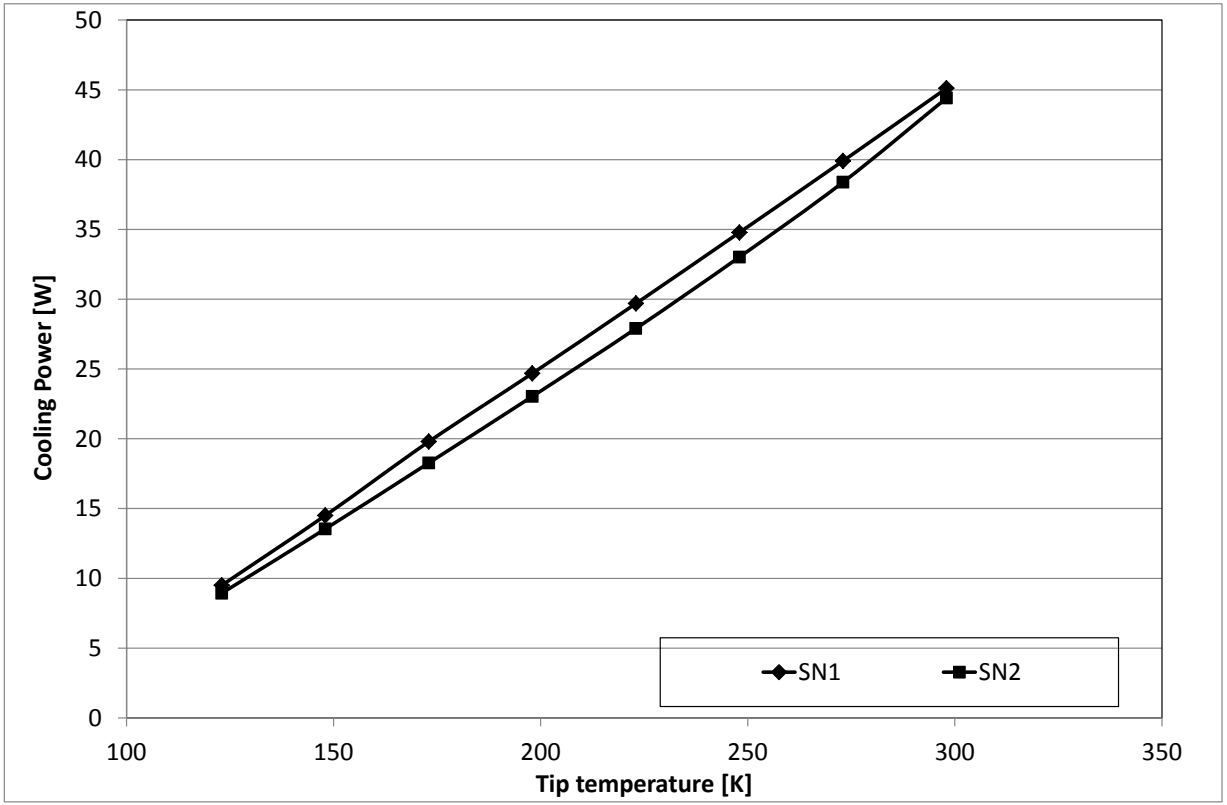




Cooling power at 223 K (qualification result)



Cooling power at 150 C, 175 W AC



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Conclusion on Part 1

- Cooler designed for 150 C ambient
- While designed for 223 K working point, still significant heat lift available at cryogenic temperatures
- 20 coolers built to date
- More details to be presented at ICC 20, 2018

… And now for something completely different

Cryocoolers for Extreme Mechanical Environments

Different types of extreme mechanical environments can be envisioned

- Short duration, high levels (e.g. launch levels for space)
- Significant levels, high portion of operating life

We will focus the discussion on applications with significant random vibration levels during the operating life of the product, e.g.:

- Next-gen fighter aircraft
- UAV
- Specific vehicles

Why does the classical test approach not suffice?

Classical test approach (e.g. MIL-STD-810G 514.6):

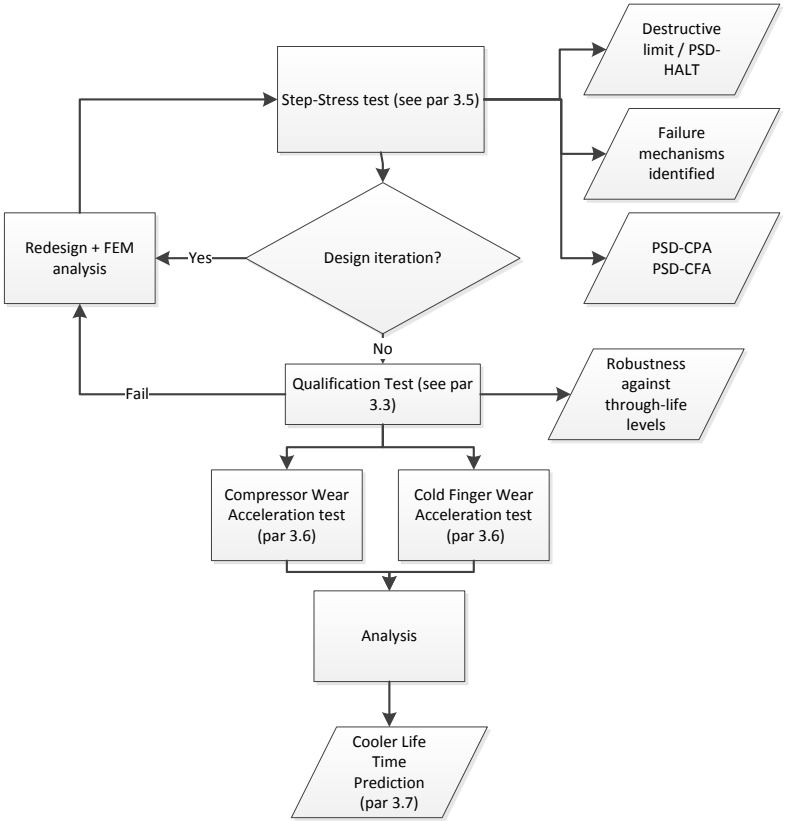
- Apply a time-condensed spectrum to the product
- Time-condensed spectrum is assumed representative for exposure during product life
- Disadvantage: Not a realistic assessment of effect on life time or reliability of a cryocooler

HALT test approach:

- Pneumatic hammers, 6-axis exposure, and (typically) temperature shocks
- "Shake until it breaks", find weak spots in design, suitable for iterative development approach
- Disadvantage: Link between applied vibrations and application level lost

Alternative approach proposed

- Cohesive set of tests from development phase to qualification to life time testing
- Inputs used in subsequent phases



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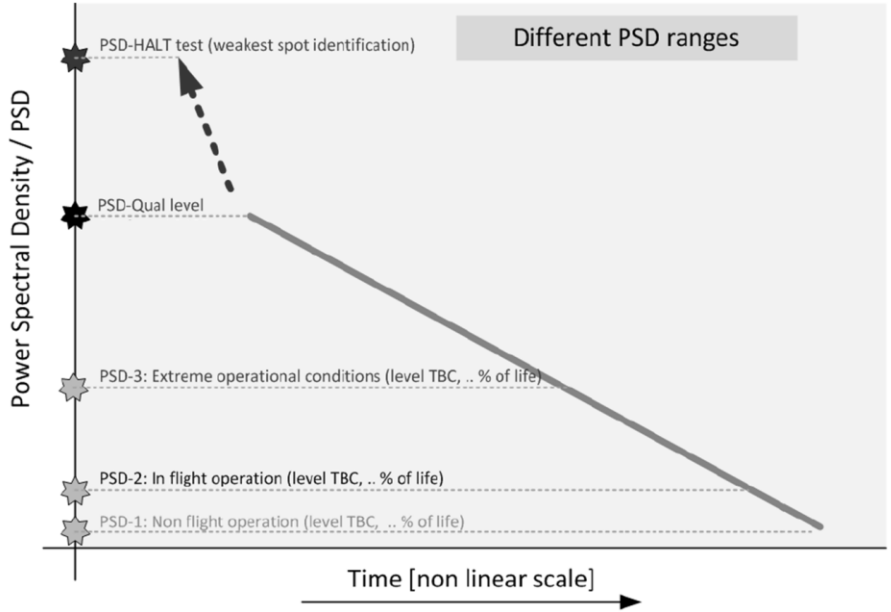
Step stress test approach

Increase power level to determine:

- Level at which cooler performance impacted
- Level at which cooler no longer functions
- Level at which cooler breaks (limit level, to be compared to FEA)

A clear link should be present to PSD levels in the actual application, as well as qualification (scaling)



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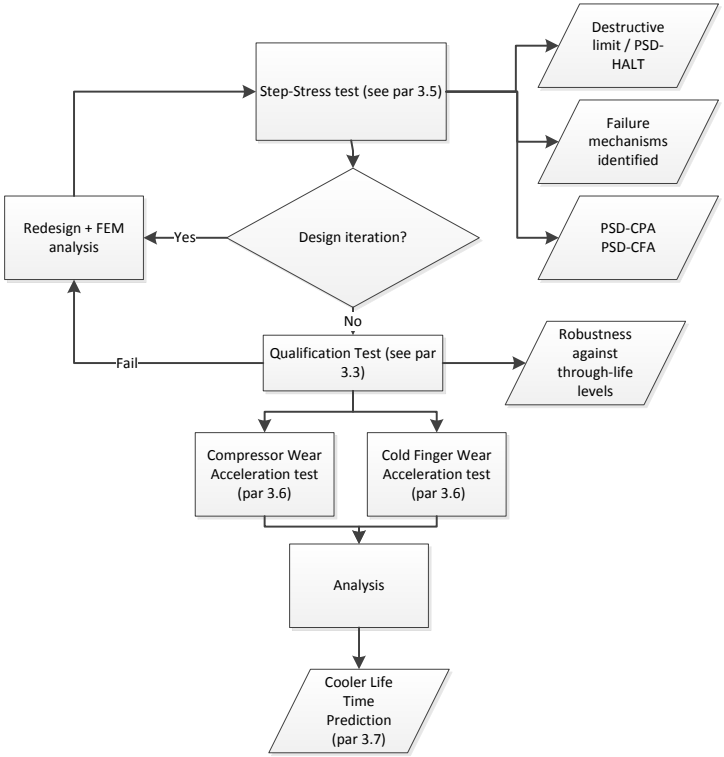
After step-test

Analysis to determine:

- Subsystem affected:
  - PSD-CFA for cold finger affected
  - PSD-CPA for compressor affected
- Potential design iterations
  - Substitute for HALT test

If no further iteration needed, start QUAL test



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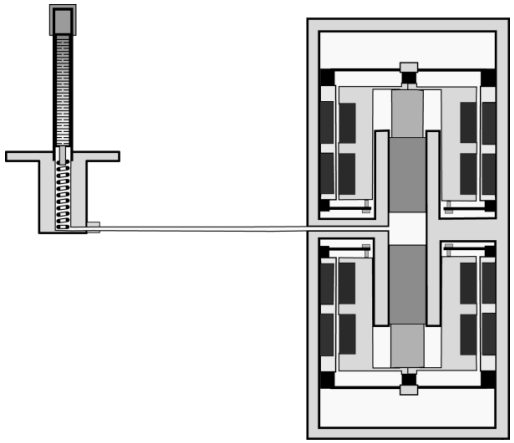
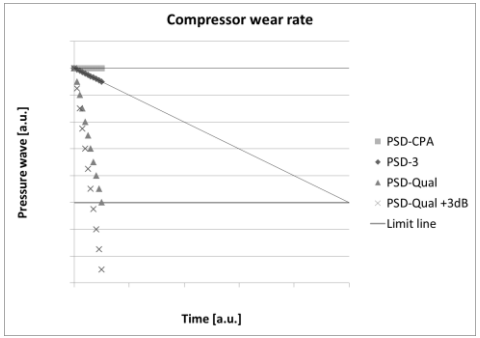
Accelerated life time test based on PSD-CFA and PSD-CPA

PSD level higher than application for accelerated endurance test

Acceleration factor cannot be assumed the same for compressor and cold finger

- Flexure bearing compressor: radial stiffness and bumpers will prevent any influence up to a point
- Pneumatic cold finger: load on bearing increased due to mechanical environment





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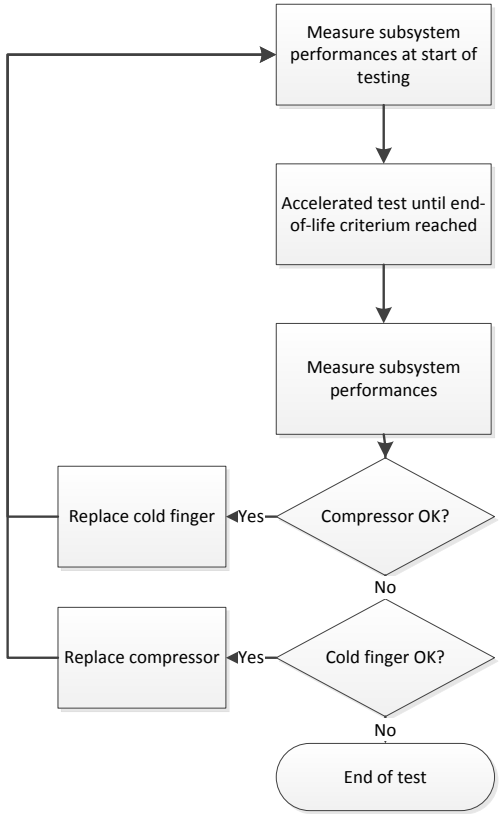
Life time test approach: Subsystem level testing

Test until cooler performance NOK

- Analyse impact on both subsystems (compressor / cold finger)
- Replace only the failed component and restart test
- Review and adjust test level for next leg

Result:

- More accurate estimate of effect of specific PSD levels on cryocooler life time (scaling)



Conclusion (2)

- **An integral test methodology is proposed for design, qualification and life time testing for cryocoolers subjected to extreme mechanical conditions over their operating life time**

Two different subjects presented…

Questions?

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