Jet Propulsion Laboratory
California Institute of Technology

Characterization Testing of Lockheed Martin Micro1-2 Cryocoolers Optimized for 220 K Environment

I.M. McKinley, M.A. Mok, D.L. Johnson, and J.I. Rodriguez

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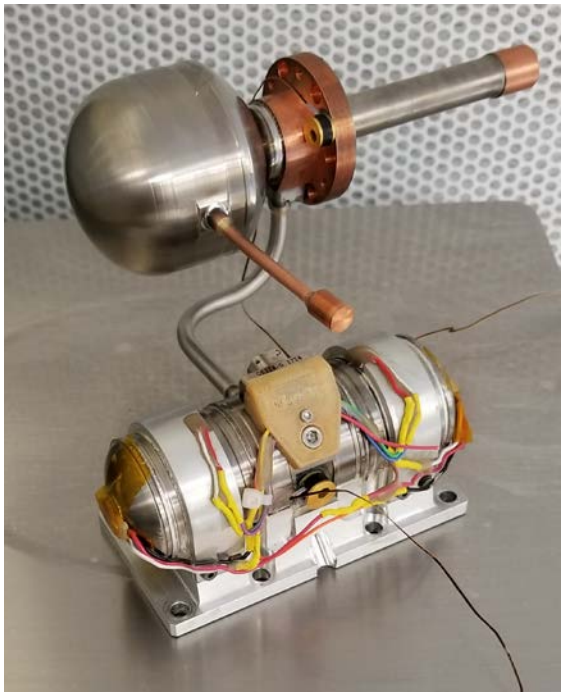
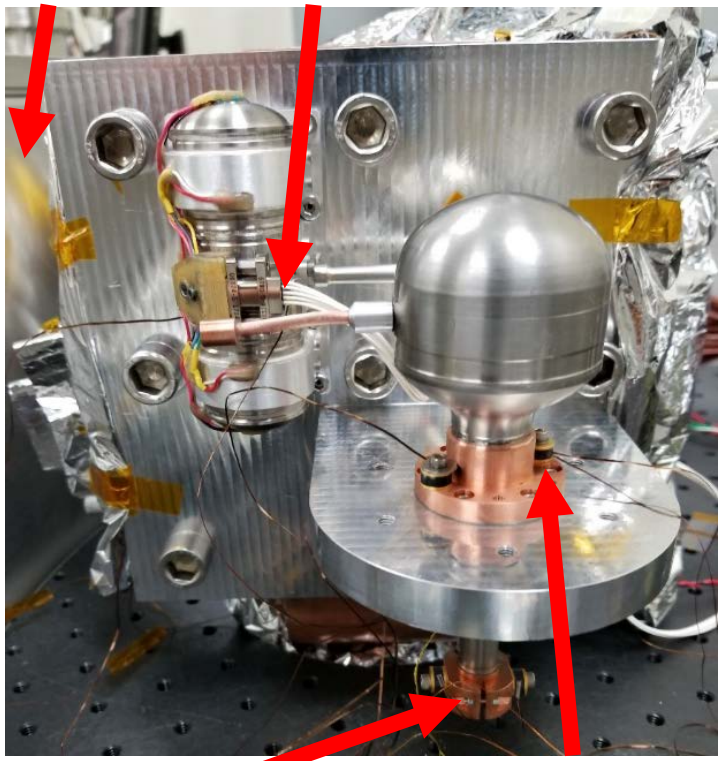
Lockheed Martin Micro1-2 MISE Prototype Cryocooler

- The Jet Propulsion Laboratory procured two prototypes for the Mapping Imaging Spectrometer for Europa (MISE) Instrument on the Europa Clipper
- Characterization tests were performed to assess the cooler's compatibility with the environmental requirements of the Europa Clipper as well as assess its performance in the expected thermal environment



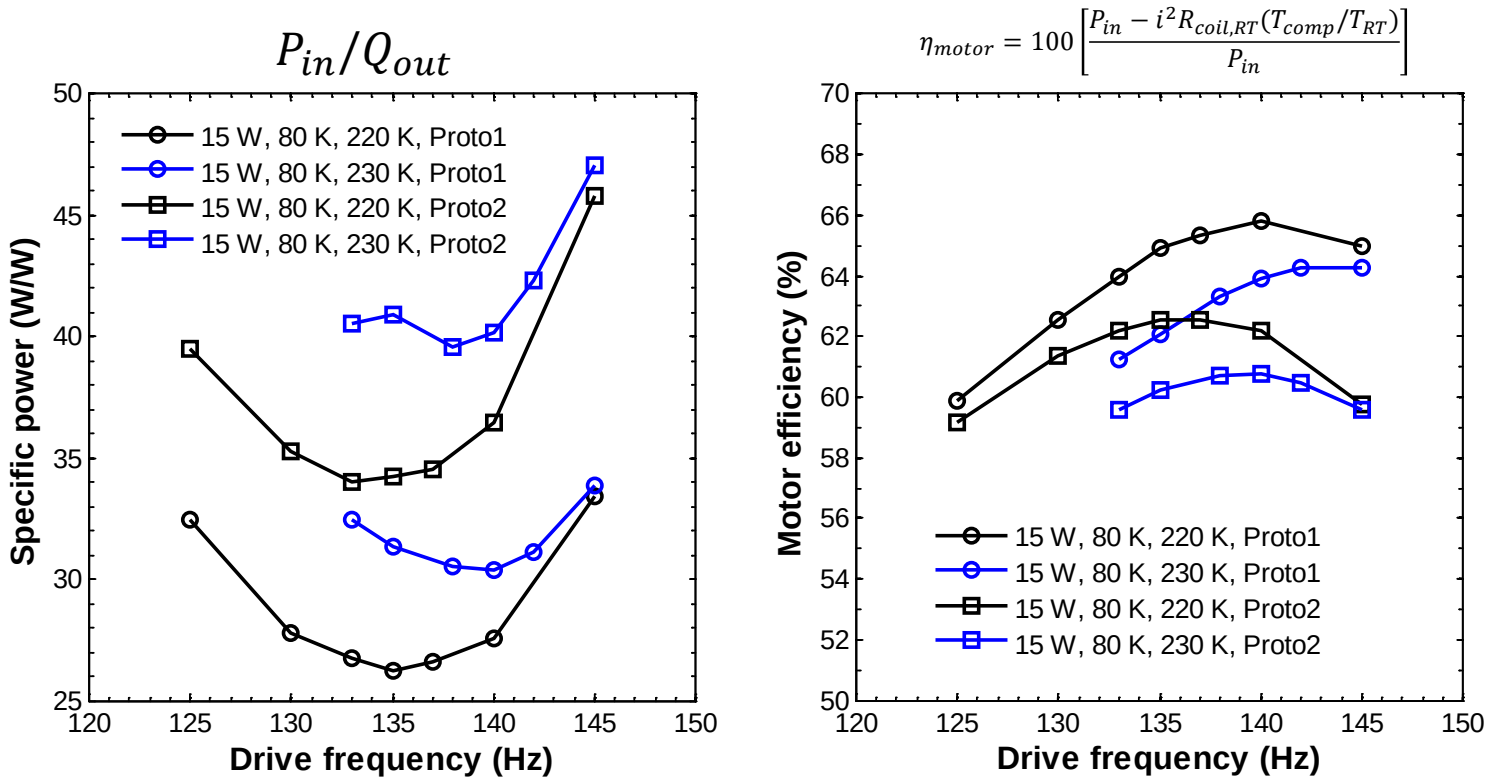
- Pulse tube type
- Flexure bearings
- Maturity level: TRL 6 for Earth and Europa
- Mass: 480 grams
- Compressor: 92 mm long
- Ti cold finger: 160 mm long
- 60 W maximum input power
- 800 psi He fill pressure
- Optimized for:
  - 80 K cold tip
  - 135 Hz drive frequency
  - 220 K heat rejection temperature

Thermal Vacuum Performance Testing



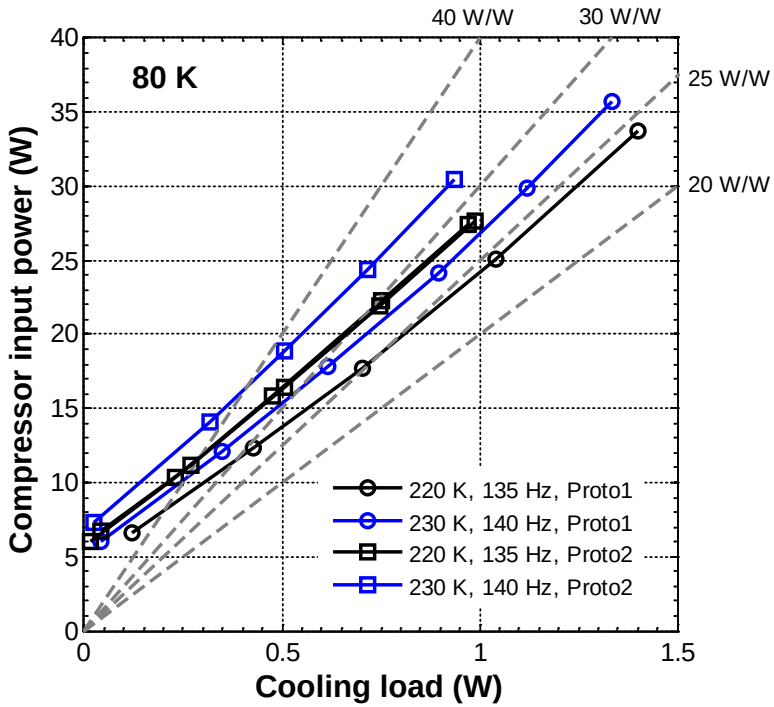
- Parametric study:
  - Frequency: 125 Hz to 145 Hz
  - Heat rejection temperature: 220 K to 230 K
  - Input power: 5 to 40 W
  - Heat lift: 0 W to 1.5 W
- Not shown:
  - Cold tip: MLI
  - MLI surrounding cooler
- Compressor temperature was <5 K higher than expander temperature
- Cooler driven with Chroma 61602 AC power supply

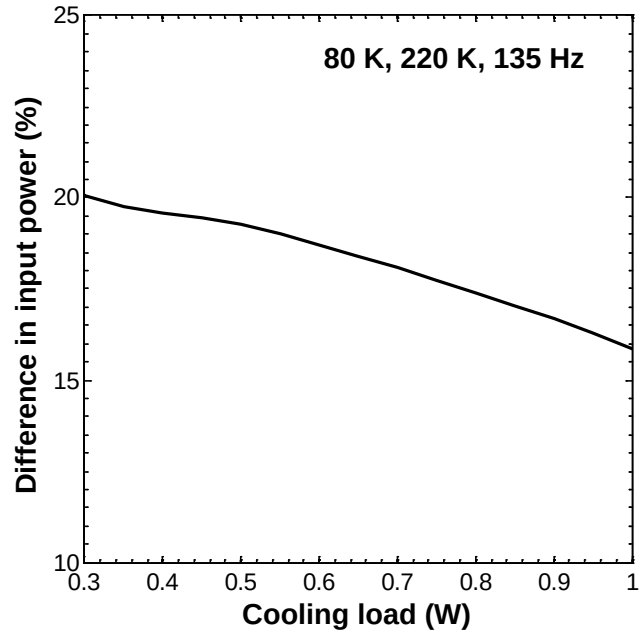
Effect of Drive Frequency



- 135 Hz desired optimal drive frequency at 220 K reject achieved for both prototype coolers
- For a given set of conditions, minimum specific power and maximum motor efficiency occur at nearly the same frequency

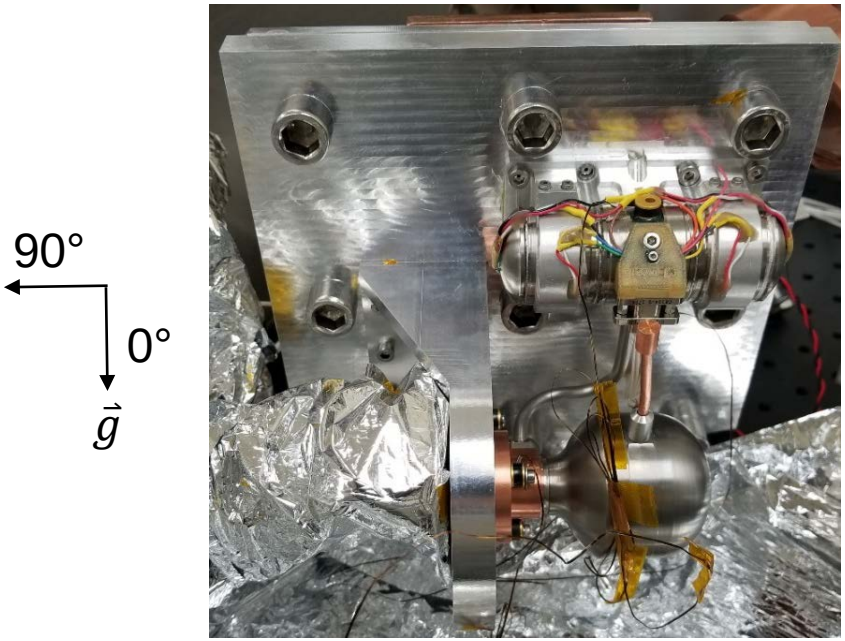
Performance Comparison at 80 K Cold Tip

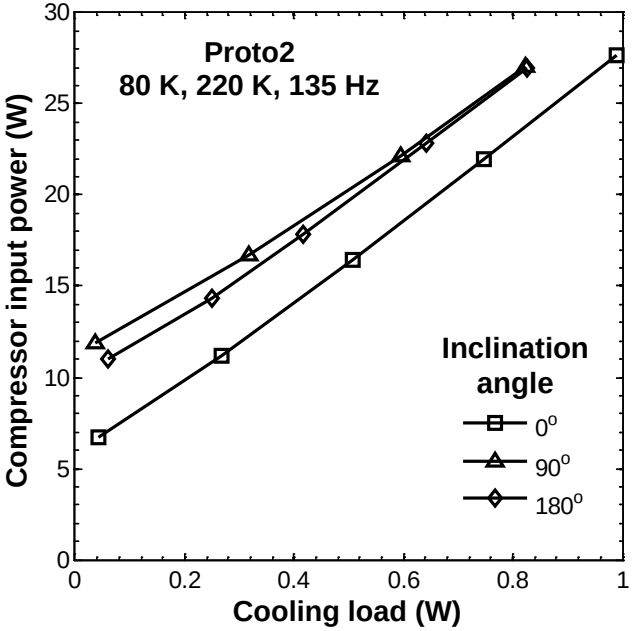




- Proto1 outperformed Proto2 for all measured conditions
- The difference in input power between the two coolers for nominal conditions was between 17% and 20%
- Effect of compressor temp +/-10 K from 220 K expander is negligible

Effect of Pulse Tube Inclination Angle

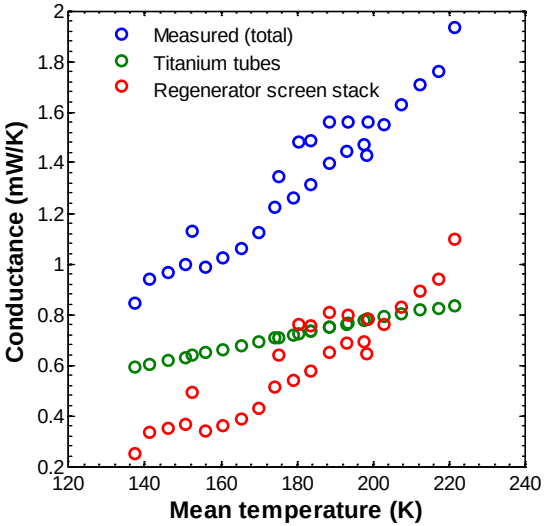




- The cooling load at 90° and 180° was nearly identical for input power above 20 W
- At 300 K reject temperature 120° inclination angle had the worst performance for a given input power and cold tip temperature

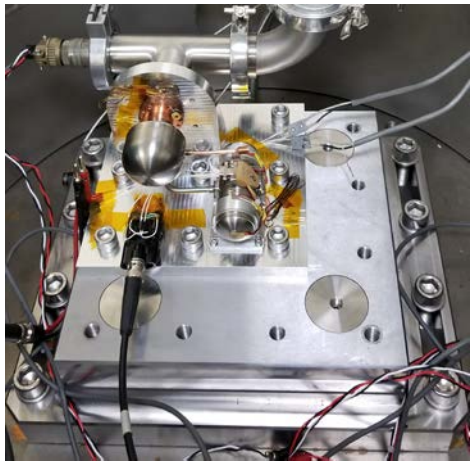
Off-State Conductance

- Cold tip at 180° inclination angle
- Radiation shield implemented
- Heat applied at cold tip
  - Warmer than expander
  - Minimize natural convection in pulse tube
- Measured for fixed
  - Q= 18 mW
  - Q= 37 mW
  - $T_{cold\ tip}$= 208 K
- Titanium tube conductance calculated based on geometry of tubes
- Conductance increased linearly with temperature
  - Consistent with the trend of the thermal conductivity of stainless steel and titanium
- Gas conduction of helium negligible

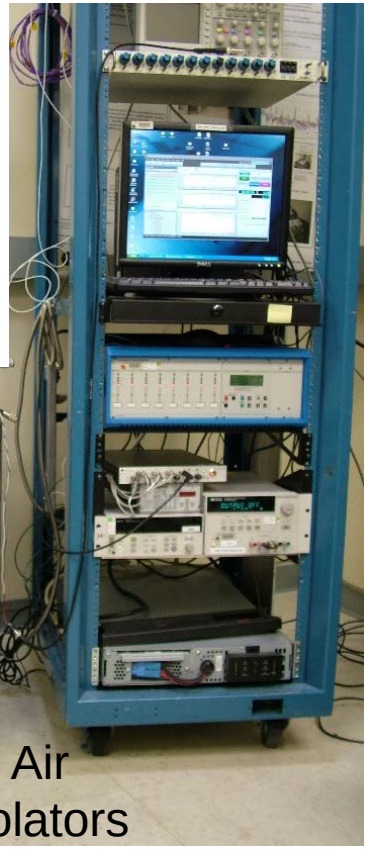


Measurement of Exported Forces and Torques

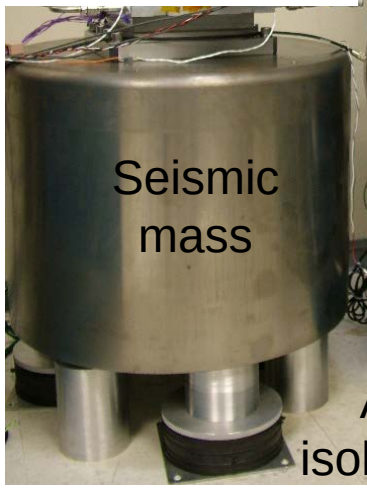
Vacuum valve



Rack electronics



Dynamometer

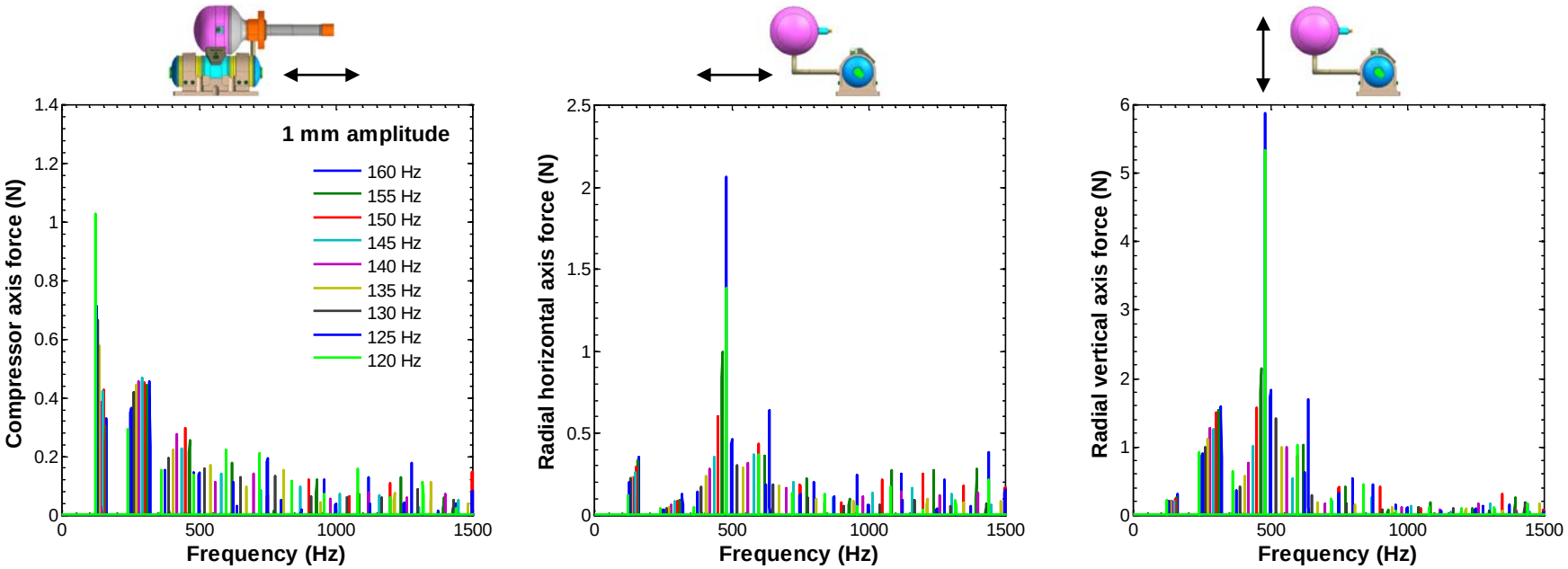


Seismic mass

Air isolators

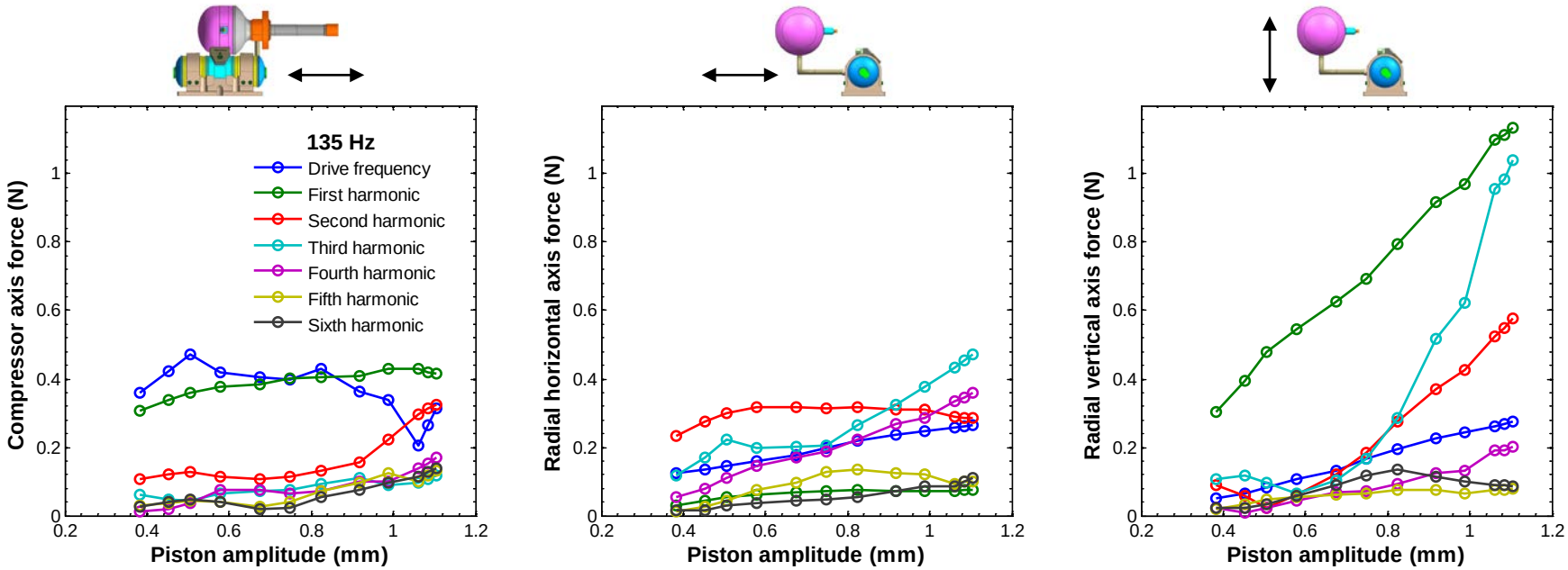
- Parametric study:
  - Drive frequency
  - Input power
- Cold tip under vacuum
- Room temperature heat reject
- Rigid mounting
- Cooler driven with Chroma 61602 AC supply

Effect of Drive Frequency on Exported Forces



- Proto1 and Proto2 showed similar behavior
- Radial mode in the compressor at 480 Hz
  - Second harmonic of 160 Hz and third of 120 Hz
- Frequency of radial mode was dependent on piston amplitude

Effect of Piston Amplitude on Exported Forces

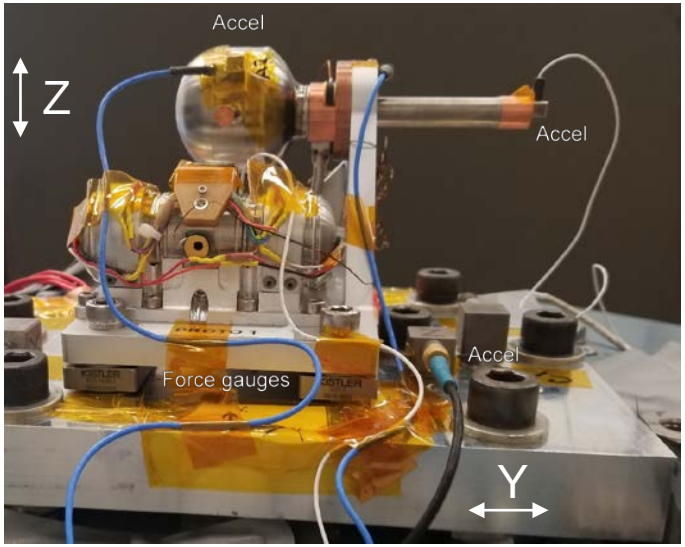


- Cooler running off-resonance at 300 K
  - Optimal drive frequency: 157 Hz at 300 K
- Proto1: 1st harmonic vertical axis linear increase with amplitude
  - Proto2 did not have this feature: 3rd harmonic largest for all amplitudes
- Proto2 compressor axis force between 0.6 N and 1.3 N in this range

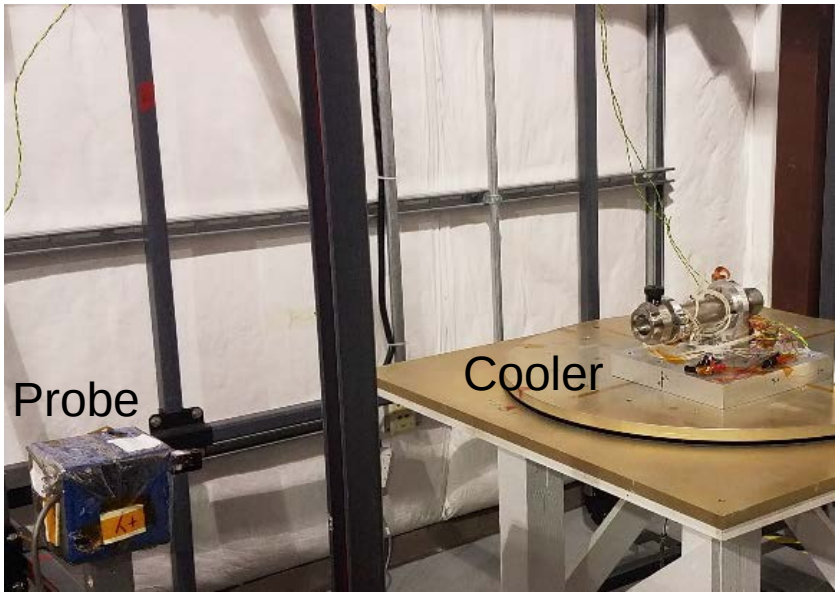
Random Vibration Testing

- GEVS PF levels
  - Response limited: cold tip mode ~500 Hz
  - Force limited: fixture modes ~750 Hz
- No mass on cold tip for full level
  - Low level: 22 gram mass on cold tip shifted mode to ~300 Hz
- Coils shorted for full level
  - Low level: coils unshorted ~50 Hz slosh mode
  - Scaling of piston position sensors indicate that unshorted at full level would yield contact with end-stops
- Pre and post RV cooler performance within measurement error
  - 80 K, 220 K, 135 Hz

Frequency (Hz)	Acceleration (g^2/Hz)
20-50	+6 dB/oct
50 - 800	0.16 g^2/Hz
800 - 2,000	-6 dB/oct
Overall	14.1 G_{RMS}
Duration	60 Seconds



Electromagnetic Interference



- DC:
  - Maximum radial 0-pk field strength of 11 nT at 1 meter
  - Total quadrupole moment of 14.38 mA-m^2 operating at 55 W
    - Increased to 14.68 mA-m^2 when not operating
  - Slightly larger fields than Micro1-2 cooler which was 10.33 mA-m^2
    - Different motor ironworks
- AC:
  - 68 dBpT rms peak at operating frequency 157 Hz measured at 1 meter
    - Similar to Micro1-2 cooler with different ironworks

Conclusions and Future Work

- Thermal performance of the cooler optimized for 135 Hz, 220 K environment, operating at 80 K was as expected
- Exported forces were comparable to past Lockheed Martin microcoolers
- Electromagnetic interference was comparable to past Lockheed Martin microcoolers
- Cooler successfully survived GEVS PF random vibration
- Off-state conductance of cold finger was very small
- The MISE Instrument plans to proceed with a flight build of this cooler

Thank you for your attention

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Questions?

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