Vibration Analysis of the SuperCDMS Dry Dilution Refrigerator
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Introduction
- Dark matter is an unknown entity that accounts for approximately 85% of the matter in the universe.
- SuperCDMS (Cryogenic Dark Matter Search) hunts for a dark matter particle candidate using cryogenic semiconductor detectors at 40 mK.
- The Queen’s University SuperCDMS test facility incorporates a dry dilution refrigerator (DDR), similar to what will be used for SuperCDMS SNOLAB and the Cryogenic Underground Test facility (CUTE) in the near future (also at SNOLAB).
- Operation of DDGs is less expensive and easier than DRs with liquid helium [1]; however, the pulse tube cooler (PT) introduces vibrations.
- Vibration induced noise limited the sensitivity of the previous phase of SuperCDMS at Soudan [2].

Experimental Methods
- Equipped Queen’s DDR with three single axis accelerometers near the location of the detectors, and a triaxial accelerometer on the top plate for reference.
- Developed and designed data acquisition systems.
- Cross calibrated accelerometers while mounted together.
- Performed two different types of measurements with induced vibrations. Broadband vibrations produced with the pulse tube on/off and frequency sweeps using a shaker.

Finite Element Analysis
- Created CAD model with Autodesk Inventor based on the Queen’s DDR.
- Meshed the CAD model, and defined material properties and boundary conditions prior to the analysis.
- Performed a modal analysis on the CAD model using the FEA software Simulation Mechanical.
- The FEA predicts low frequency pendulum modes and more complex modes at higher frequencies.
- FEA results can be compared to experimental measurements with accelerometers.

Analysis & Results
- Calculated power spectral densities (PSD) for each measurement.

\[ \text{PSD} = \frac{F^2}{f_n^{\text{FFT}}} \]

\( F \) is the FFT, \( f \) is the sampling rate, and \( n^{\text{FFT}} \) is the number of bins used in the FFT.

- PT on/off measurements (figure on left) clearly show low frequency modes (~10 Hz) in x-y plane: pendulum modes predicted by FEA.
- Frequency sweeps (figure on right): calculate transfer functions between top and base plate (using PSDs corrected for intrinsic noise and relative response of the different accelerometers).

Future Work
- This study may be repeated in the future at CUTE to develop vibration specifications and mitigate their impact for SuperCDMS SNOLAB.
- Different vibration measurement techniques may be investigated to increase the sensitivity of this experiment and provide improved results.
- Study sensitivity of new SuperCDMS detectors to vibrational noise and compare to similar measurements done with old SuperCDMS detectors by the SuperCDMS group at Berkeley [3].
- Monitoring vibrations during detector operations will help reduce their impact on the sensitivity of the experiment.

References

Accelerometers used: Endevco 2271A, Endevco 45A