Vibration Analysis of the SuperCDMS Dry Dilution Refrigerator

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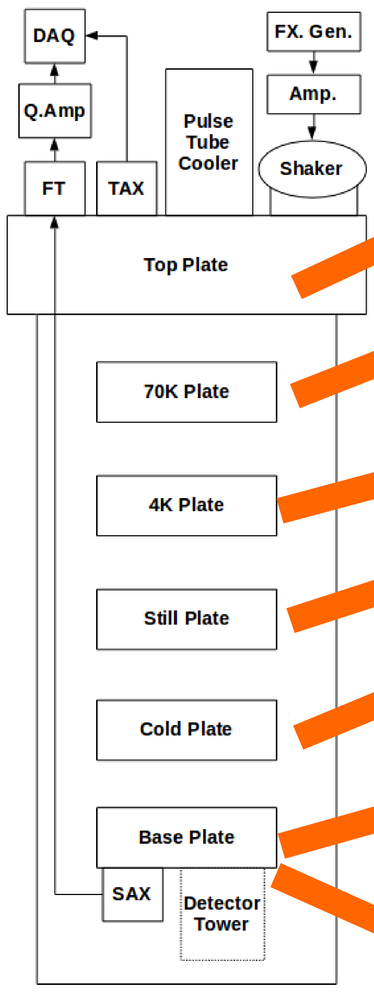
Introduction

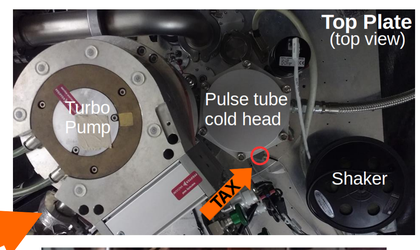
- Dark matter is an unknown entity that accounts for approximately 85% of the matter in the universe.
- SuperCDMS (Cryogenic Dark Matter Search) hunts for a dark matter particle candidate using cryogenic semiconductor detectors at 40 mK.
- The Queen's University SuperCDMS test facility incorporates a 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 DDRs 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].

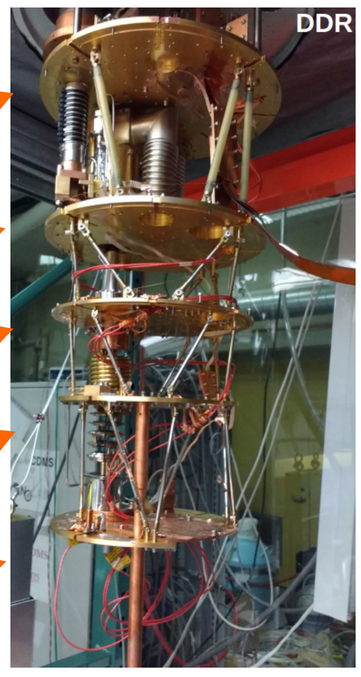
Experimental Methods

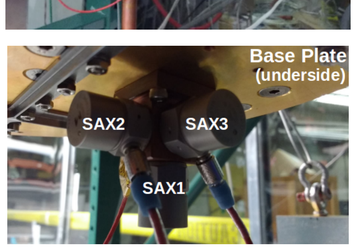
- Equipped Queen's DDR with three single axis accelerometers near the location of the detectors, and a triaxial accelerometer on the top plate for reference.
- Developed and designed data acquisition systems.
- Cross calibrated accelerometers while mounted together.
- Performed two different types of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



Block diagram of vibration measurement system for Queen's DDR.

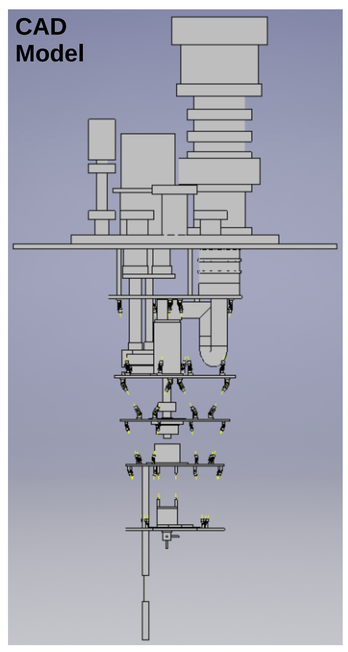


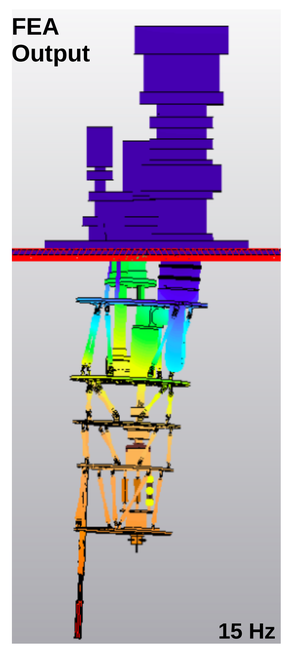


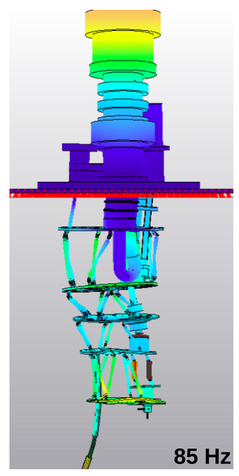


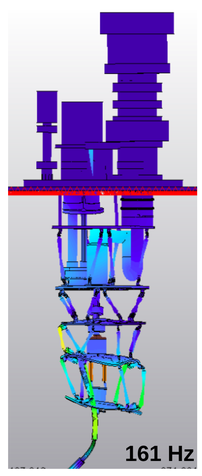
Finite Element Analysis

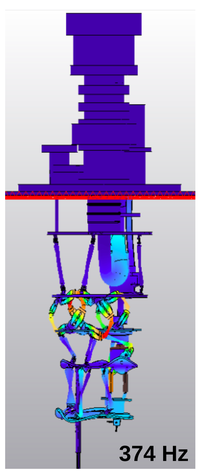
- Created CAD model with *Autodesk Inventor* based on the Queen's DDR.
- Meshed the CAD model, and defined material properties and boundary conditions prior to the analysis.
- Performed a modal analysis on the CAD model using the FEA software *Simulation Mechanical*.
- The FEA predicts low frequency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



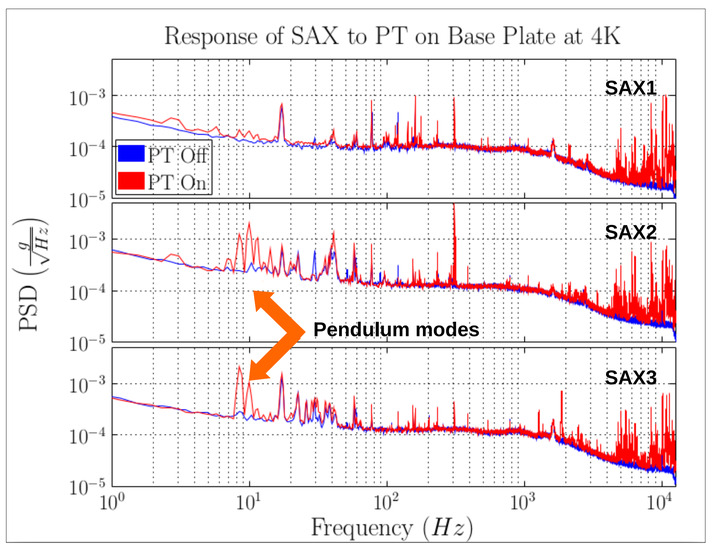








Analysis & Results



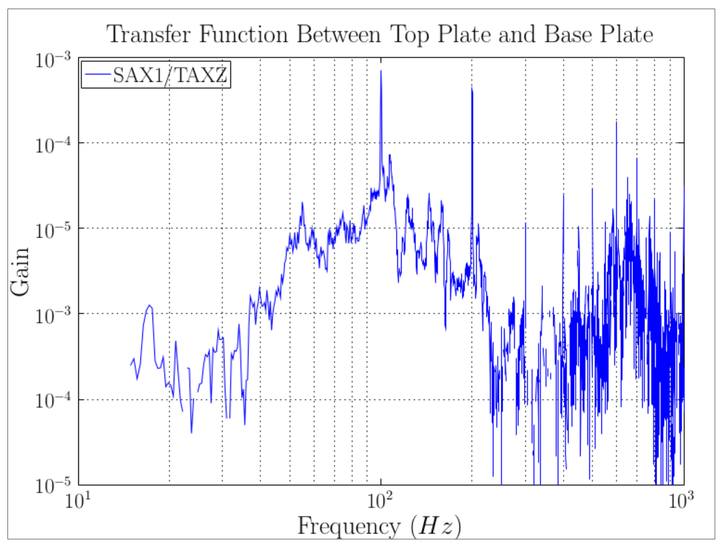
PSDs of each SAX on the base plate at 4K with the pulse tube on and off. The accelerometers parallel to the plate show increased vibrations at about 10 Hz, indicating possible pendulum modes.

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

$$PSD = \sqrt{\frac{|F|^2}{f_s n_{FFT}}}$$

F is the FFT, f_s is the sampling rate, and n_{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).



Transfer function between the top and the base plate for vibrations along the vertical axis. A set of harmonics (100 Hz and multiples, up to 900 Hz) is seen on top of broader resonances.

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 thier impact on the sensitivity of the experiment.

References

[1] M. Olivieri, et al. "Vibrations on pulse tube based Dry Dilution Refrigerators for low noise measurements," *Nuclear Instruments and Methods in Physics Research,* ***858***, 2017.

[2] SuperCDMS Collaboration, "WIMP-Search Results from the Second CDMSlite Run," *Phys. Rev. Lett.* **116**, 2016.

[3] M. Pyle, "Vibration Studies at UCB," SuperCDMS internal note, presented at a SuperCDMS Collaboration meeting in Minneapolis MN, August 1 2016.

Accelerometers used: Endevco 2271A, Endevco 45A