Acoustics of Failure- Finding the Density of Modes

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The Density of Modes

The density of modes tells us the number of ways a particular system can oscillate at a given frequency.

An excess of low frequency (floppy) modes- compared to Debye scaling (marked by a black line in Fig 1.) tells us that the system is not rigid.

In Figure 1: We see an excess of low frequency modes relative to Debye scaling below some characteristic frequency ω*. With decreasing pressure, this ω* decreases.

(Debye scaling is the DOM scale we expect from a special Debye solid.)

The data will be analysed using thermal relations, even though granular materials are not, in general, thermal.

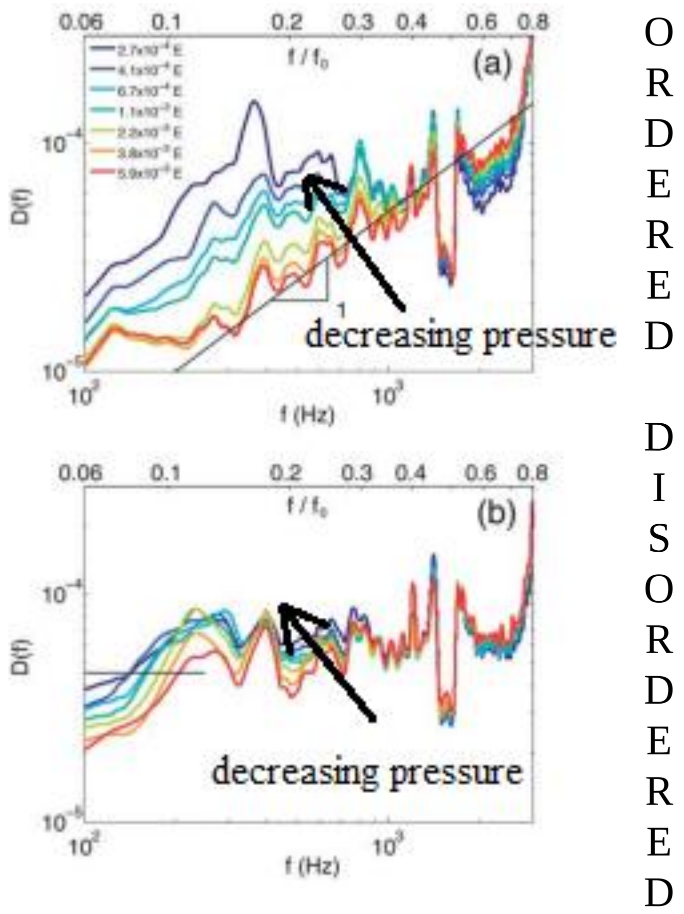


Figure 1 a and b: The DOM at 7 pressures for a) an ordered b) a disordered granular system [6] (Debye scaling is the black line)

A goal of ours is to understand **if thermal techniques can be applied to measure the density of modes for granular systems.**

$$C_v(\tau;t) \equiv \frac{\sum v_k(t+\tau)v_k(t)}{\sum v_k(t)v_k(t)},$$

Equation 1: The Velocity Autocorrelation function [1,7]

$$D(\omega;t) = \int_0^\infty C_v(\tau;t)\cos(2\pi\omega\tau)d\tau.$$

Equation 2: The Density of States[1,7]

After measuring the DOM, we would like to see **whether it is possible to use the DOM to understand the state of a material.**

To measure the DOM

- We will collect the velocities of particles
- Use the velocities to build an autocorrelation function
- Take an FFT and its real part which is the DOM.

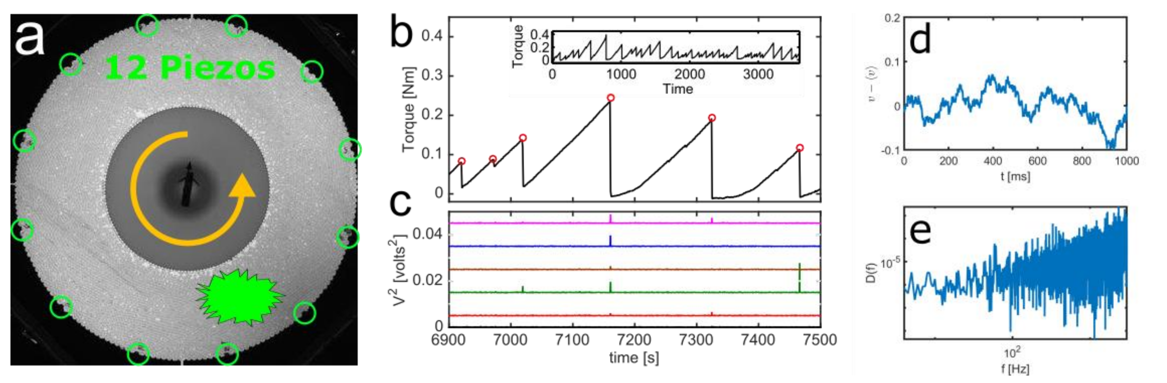


Figure 2: Failure events in time. a) Showing the experimental setup from a previous paper b & c) showing stick-slip failure events in time through measured torque, d) Showing the velocities of the particles calculated, e) Showing the density of modes calculated from the velocities.[7]

References:

[1] Dickey, J. M., and Arthur Paskin. “Computer Simulation of the Lattice Dynamics of Solids.” *Physical Review Journals Archive*, American Physical Society, 15 Dec. 1969, https://link.aps.org/doi/10.1103/PhysRev.188.1407.

[2] Fleischer, Cesca. “How Piezoelectricity Works: Eagle: Blog.” *Eagle Blog*, 2 Feb. 2021, https://www.autodesk.com/products/eagle/blog/piezoelectricity/.

[3] Gallery, Landslide. “Landslides- Significant Natural Hazards and Southern BC.” *Landslides - Significant Natural Hazards in Southern B.C.*, 2019, http://www.sfu.ca/geog/geog351spring09/group06/Landslide/2landslidediagram.htm.

[5] Nelson, Stephen. “Natural Disasters.” *EQ Case Histories*, http://www2.tulane.edu/~sanelson/Natural_Disasters/eqcasehist.htm.

[6] Owens, Eli T., and Karen E. Daniels. “Acoustic Measurement of a Granular Density of Modes.” *Soft Matter*, The Royal Society of Chemistry, 27 Nov. 2012, https://pubs.rsc.org/en/content/articlelanding/2013/sm/c2sm27122b.

[7] Theodore A. Brzinski, III, and Karen E. Daniels. “Sounds of Failure: Passive Acoustic Measurements of Excited Vibrational Modes.” *Physical Review Letters*, American Physical Society, 25 May 2018, https://link.aps.org/doi/10.1103/PhysRevLett.120.218003.

Sensor Design

The piezoelectric sensors that we use consist of two parts.

The cells are placed in the shaker- and are used to measure voltage

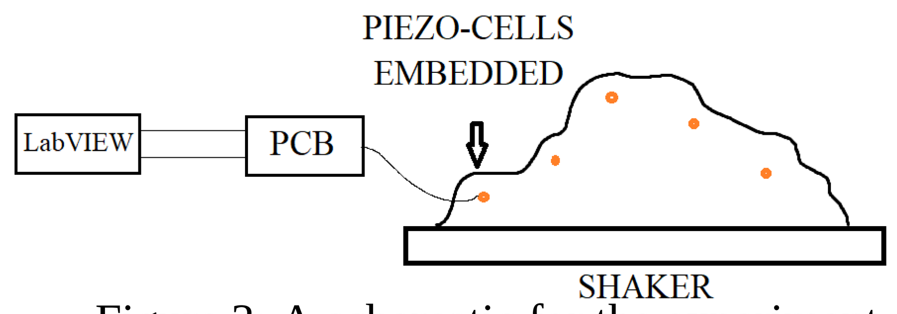
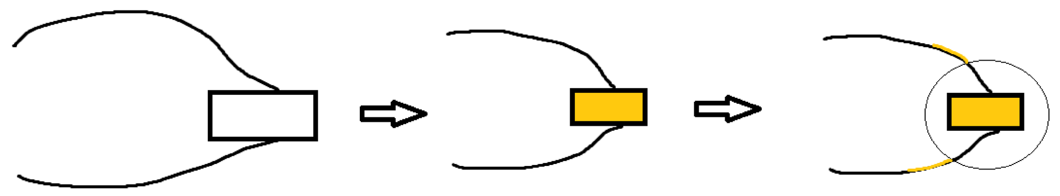


Figure 3: A schematic for the experiment

The voltage is used to create the VCAF and find the DOM.

Creating Piezoelectric Cells



A thin wire is soldered to the cells

The cells are painted to prevent the flux from interacting with the polyurethane

A polyurethane cast is used to cover the cells. Finally the wires are painted to prevent shorting.

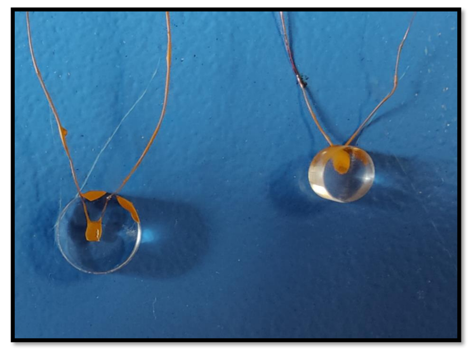


Figure 4: Finished examples of cells

Piezoelectric cells consist of a special lattice. When squashed or stretched, the symmetry is offset, and a dipole moment is formed. This can be measured as a potential difference.

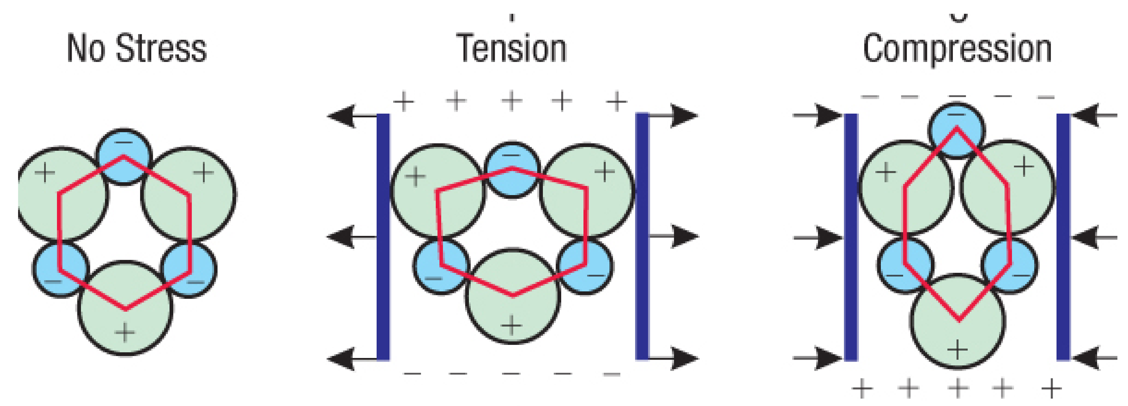


Figure 5: An example of a squashed and stretched lattice forming a dipole vector [2]

Measuring piezoelectric voltage

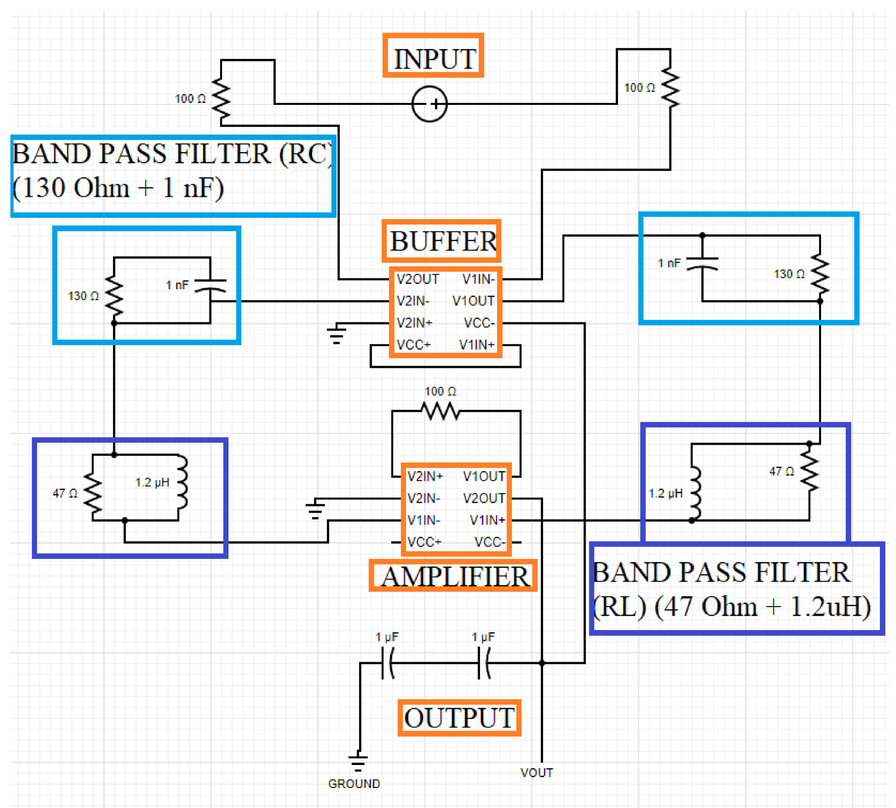


Figure 6: The labelled circuit diagram

The circuit board was designed in EAGLECAD, consisting of a series of 2 bandpass filters (one RC and one RL), one preamplifier and amplifier.

We measure the piezoelectric charge difference and amplify it- measuring it as a voltage.

The voltage values are collected through a LabVIEW input dock.

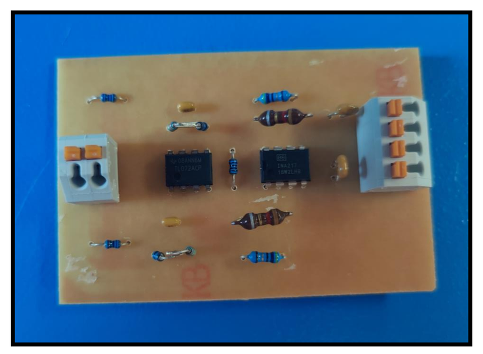


Figure 7: A finished example of a PCB

Acoustic Driving

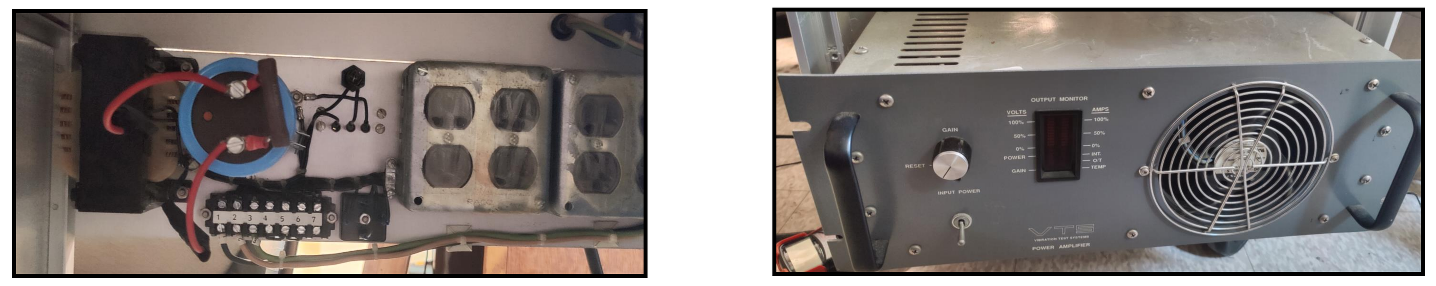
The amplifier interlocks were disabled manually, and the power panel was wired to the amplifier, hence bypassing the second interlocks.

A 120V 30A provides sufficient power to run the shaker for some time. (~30 mins)

It is important to drive the system with broad spectrum white noise to measure a response, because we measure the DOM as a function of f.

Therefore, driving the system at many frequencies tells us about what the DOM looks like.

Figure 8: The industrial shaker- VGS500



Figures 9 and 10: The PP-7 Power panel and PA1200 Amplifier

Outlook

The piezoelectric cells will be placed inside the shaker, and their voltage output will be amplified through the amplifier circuit. The amplified voltages will be collected using the LabVIEW dock, and then used to find the Density of Modes in MATLAB.

We would like to verify the underlying physics behind the density of states in granular materials, and better understand what the DOM tells us. This will allow us to translate the technique to natural systems.

Figure 12: A fault lines in a small earthquake [3]

Since most natural disasters affect the granular earth in some way, embedding such sensors in soil is a good source of information on the DOM of the environment.

This will allow for the prediction of many natural disasters that cause vibrations in granular materials in the environment.

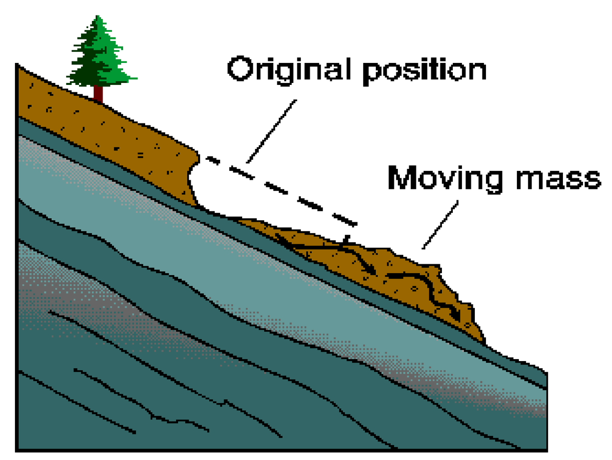


Figure 11: A landslide [3]

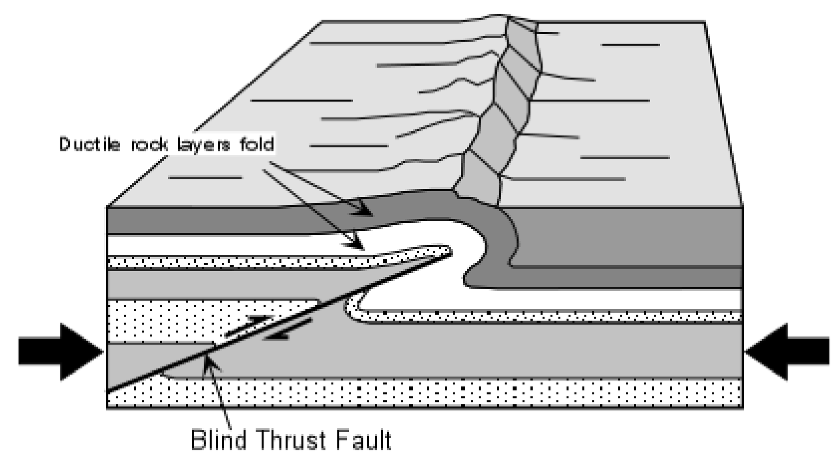


Figure 12: A seismic fault [5]