Cymatics
Chladni Plate

Flow Visualization
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Group Project 1

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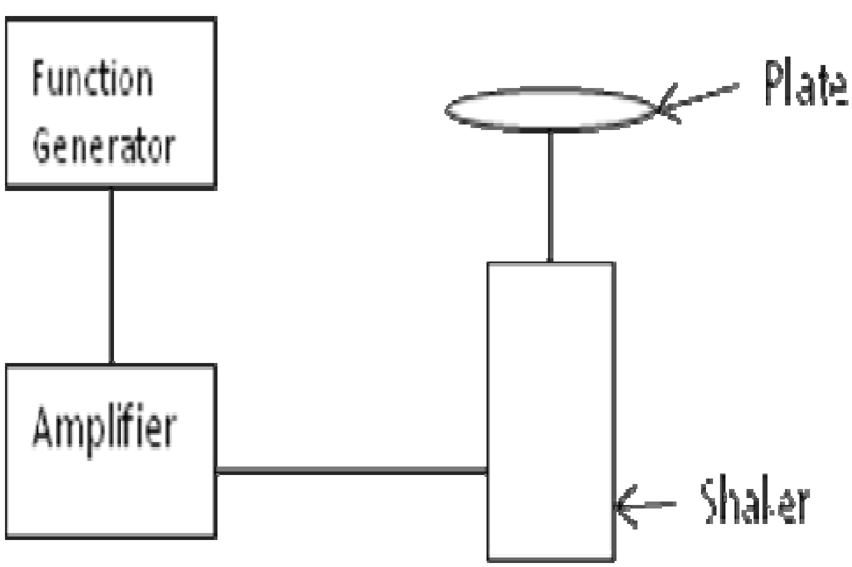
For our first group project we decided to create an experiment allowing us to view and study the field known as Cymatics. “Cymatics (from Greek κῦμα "wave"), also known as modal phenomena, is the study of visible sound and vibration, typically on the surface of a plate, diaphragm, or membrane. Directly visualizing vibrations involves using sound to excite media often in the form of particles, pastes, and liquids (1). In our experiment we used a device known as a Chladni plate. This device receives its name from Ernst Chladni, a German musician and physicist, who perfected Robert Hooke’s experiment of drawing a bow across the edge of a metal plate covered in sand or flour and viewing the appearance of the nodal patterns (2). For our experiment we wanted to create a Chladni plate system that allowed us to create varying nodal patterns and view how the sand shifted as the nodal patterns changed.

To create our Chladni plate set up we used a function generator to control the frequency and amplitude of our wave. This was then run through an amplifier to allow for more control over the amplitude. The amplifier was hooked up to a shaker that supported our plate, which was a 14 in. pizza tray, on a rod allowing the waves to propagate through the plate. The set up can be viewed in the diagram below. Using this set up, we were able to control the vibrations output from the shaker with the function generator and observe the changing nodal patterns created in the salt on our plate. The plate was bolted to the pole to hold it in place and allow the waves to properly propagate the waves through it. In order to view the nodal patterns, in the dyed milk, created by exciting it with music from a didgeridoo we simply substituted the function generator for a laptop and output the music into the amplifier.



All materials have a set of resonant frequencies which create standing waves in symmetrical patterns. These waves are comprised of nodes and antinodes [3]. The nodes are areas where the wave amplitude is zero, and are surrounded by antinodes, which are areas where the wave amplitude is a maximum. Because of this, the nodes are areas of lower energy while the antinodes are areas of high energy [4]. The salt we placed on our plate is therefore pushed off the antinodes (max amplitude, high energy areas), to the nodes (zero amplitude, low energy areas). As the frequency is increased the number of nodes increases leading to more and more complex patterns.

In our experiment we used salt to visualize the nodal patterns that were created. Typically sand is used but salt works just as well, is easy to obtain and contrasts well due to its bright white color. We spray painted our plate a deep blue to add contrast between the plate and the salt to help visualize the patterns. For visualizing with liquid, milk was used since it is slightly more viscous than water and allowed for better visualization. It was also dyed so as to increase the shadows and highlights being reflected from the sunlight, this also helped visualize what was going on. For the salt images, the camera was placed overhead looking down at a sixty degree angle. Since it was slightly after noon the sun was high in the sky and allowed us to avoid any shadowing. For the milk part, the camera was placed looking almost horizontally across the plate into the sun so as to capture as much reflection as possible, which would help highlight the distortion in the milk.

All three videos were filmed with the same camera, a SONY HVR-HD1000U. All the videos were filmed in HDV format at 1080i and then captured using Final Cut Pro and exported as .mov files. In all the videos the field of view was zoomed in to show the plate with as tight a shot as possible. This was done to show the events on the plate with as much clarity as possible since that is what we were interested in. The resolution was based on the 1080i format which means a screen size of 1920 x 1080 pixels. For the sand videos the distance from the subject to the lens was about a meter and for the milk video it was about one and a half feet.

Josh's Video

For my video I took the film of our entire second run and used that to create my final video. I did all my video editing using Final Cut Pro. I added in several title screens at the beginning and end of the film and joined it all together using crossfades. All the crossfades are one to two seconds except for the one from the final title screen into the actuall video which I extended to four seconds to give a more gradual transition into the video itself. I cut the video several times separating parts where nothing much happened for a while from parts where the nodal patterns were changing rapidly. I then selected some of the slower parts and increased the playback speed to 400-500%. This allowed me to shorten the video and make it more interesting at the same time. I added and audio track to accompany the video and cut the end of it off to make it the same length as the video. I used a three second fade in with a three decibel transition at the beginning and a three decibel transition at the end over a five second fade out.

I really like how my video turned out. I was able to show how nodal patterns change and grow in complexity on a Chladni plate when the frequency is increased without any distracting elements. The sand contrasts really well with the blue plate helping to visualize the phenomenon and making it easier to see. When the patterns are changing you can see how the salt shifts from one pattern to the next which is very interesting. I think it looks the coolest at high frequency when the patterns are quite complex and they change rapidly from one resonant frequency to the next. If I were to repeat this experiment I would make sure and use a plate that allowed the salt to fall off the sides so as not to get large buildups of salt in certain areas as seen in the video. These areas then had to be spread out again by hand, which at first I didn't like. Watching the salt be spread back out by hand and seeing it move back to the nodal positions really helps understand what is going on but I feel the hand is distracting and looks a bit weird in the video, especially when it is sped up to 500% speed. I think the music I choose accompanies the video extremely well and I really enjoy it. I feel it adds a more artistic aspect to the video as opposed to showing it with the original sound, which provides a better context for understanding the phenomenon, but at the same times gives it a more calculated, mathematical feel, which I am trying to avoid doing in this class.

Levey's Video

The video depicting the visualization by Levey Tran was comprised of the salt cymatics footage. The video begins at lower frequencies, around 700 Hz, and increases all the way through frequencies of 2,500 Hz. The video was edited in a manner that presents the viewers with the most interesting shifts in node patterns. The video is divided into 3 sections, relatively lower frequencies (700-1,200 Hz), middle frequencies (1,500-2,000), and the higher frequencies (2,000-2,500 Hz). The clips clearly show the effect of the high frequencies on the node patterns. When viewing the video, the frequency is steadily increasing and the nodal patterns can be seen to increase in intricacy and experience rapid shifts to the low energy areas. It is very appealing because this visualization is rarely seen by people. Also at times, the particles flow and shift and it looks as if the particles as a whole are swimming in a circular direction around the plate.

The video reveals the unique nodal shapes of the plate through varying frequencies. A viewer, when given the knowledge of the increasing frequencies, will interpret the video and see that as the frequency increases, the nodal shapes become more complex and intricate, yielding beautiful patterns and showing the granular flow of salt. I love that the video shows the 'shape shifting' of the salt particles. It is not something that you visualize everyday; sound that causes vibrations in a material that is unable to be visualized (sound) and then moves the salt into unique and symmetric patterns. Most people will see a vibration moving particles in a very disorderly manner, yielding no symmetric patterns or beautiful flow. Yet, this video does exactly that, allowing the viewer to experience a 'wow' effect. The intent of the project was satisfied. Though, I do wish I had more time in my busy schedule to further understand the video editing software. When I uploaded my movie file into iMovie, the clips were missing the audio that was output by the shaker. This audio could have been useful to the viewer to coordinate sound (increasing frequency throughout the video) to the changes in the nodal patterns. This aspect could have been improved. Another thing that could have been improved was the fact that our plate could have been of a different geometry, but given the constraint of time and materials, this plate was sufficient. Overall, this project was interesting, fulfilling, and intriguing and I hope that it may inspire viewers to take a shot at this type of phenomena and see what they might obtain.

Ilya's Video

For my video, I wanted to visualize a piece of music rather than a single tone from a signal generator. After some experimenting, a didgeridoo solo seemed the most effective. Unfortunately, salt took too long to rearrange itself and there were few tones in the music to be create resonant patterns in the plate. Therefore, I chose to use liquid since it would respond faster. The choice of liquid was fluoresceine dyed milk to obscure the plate and create greater contrast. I was particularly pleased with the standing wave pattern in the liquid that was superimposed onto the nodal pattern in the plate whenever the performer "spoke to the didge".

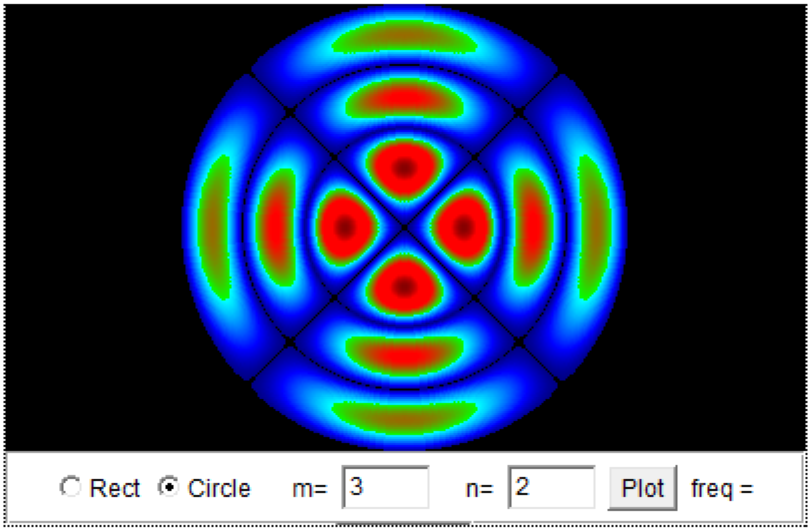
For shallow depth waves, speed of propagation is approximately

$$c = \sqrt{gy} = \sqrt{9.81\, {}^{m}/_{s^2} * 0.003m} = \frac{0.17m}{s}$$

$$\nu = \frac{V}{\lambda} = \frac{0.17\ m/s}{0.0045\ m} = 1750\ Hz$$

Unfortunately, I was not able to run an FFT to verify that the distinct sound corresponding to the pattern in fact matches the frequency calculated.

The pattern is overlaid on top of a Chladni pattern with m=3, n=2

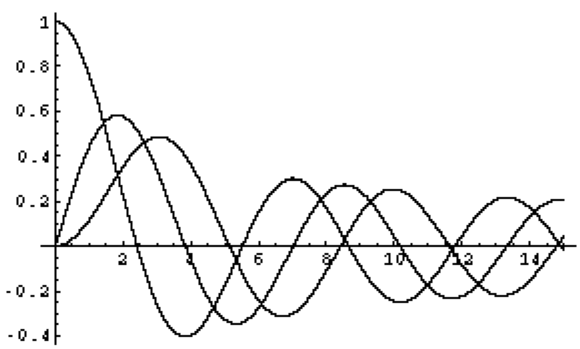


The general solution for the plate deformation is

$$u(r, \theta, t) = A * J_n(k r) \cos(n \theta) \sin(w t)$$

where $J_n(x)$ is an nth order Bessel function.

The solution, plotted against R is a sinusoid diminishing to 0 at the edge of the plate.



The video was slightly adjusted for brightness and contrast however the biggest modification was in the speed of playback. In order to show the pattern more clearly, a portion of the video was slowed down to 1/8th speed and zoom was gradually increased to show the detail of the standing waves. The wavelength of the wave pattern in the fluid was on the order of 4.5mm long based on the field of view for the video that is approximately 11.5 in. x 6.5 in. which translates into a resolution of about 160-170 pixels/in (after conversion to AVI format).

Sources:

1- Jenny, Hans (July 2001). *Cymatics: A Study of Wave Phenomena & Vibration* (3rd ed.). Macromedia Press. (From Wikpedia, the free encyclopedia: http://en.wikipedia.org/wiki/Cymatics)

2- Ernst Florens Friedrich Chladni, Institute for Learning Technologies, Columbia University. (From Wikipedia, the free encyclopedia: http://en.wikipedia.org/wiki/Ernst_Chladni#Chladni_plates)

3- The Experimental Nonlinear Physics Group, Dept. of Physics, University of Toronto: http://www.physics.utoronto.ca/~nonlin/chladni.html

4- Wikipedia, the free encyclopedia: Standing Wave: http://en.wikipedia.org/wiki/Standing_wave