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MCEN 5151

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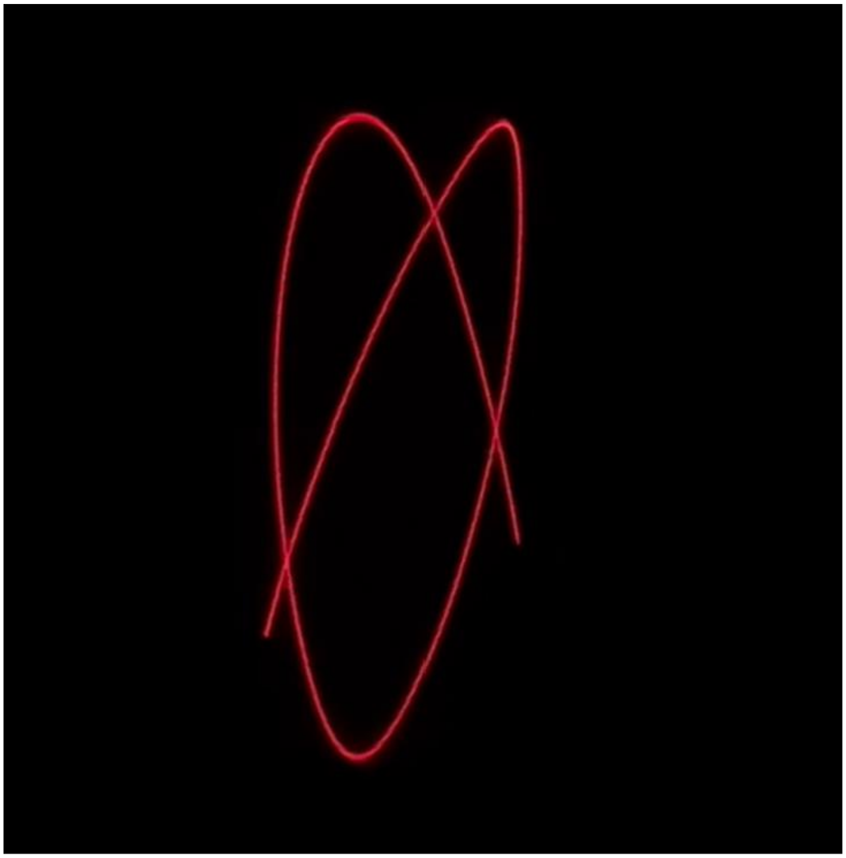
Team Third- Laser Cymatics

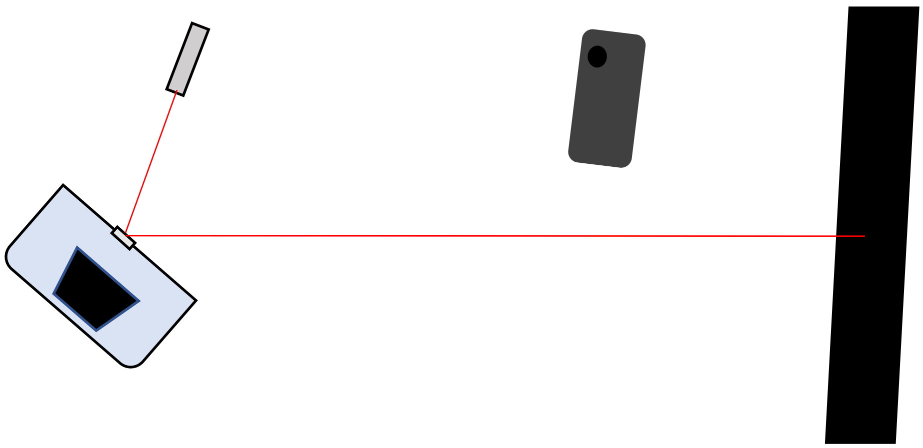


Introduction

For the third team project we decided to experiment with laser cymatics because of the interesting dynamics and variability of the experiment. Laser cymatics is the interaction of a laser and a reflective membrane that is vibrated by a speaker cone. The speaker cone induces resonance wave in the membrane that dictates where the laser reflects off of. This is similar to a Chladni plate, but instead of particulates forming in the nodes of the plate, the laser bounces off at a greater angle at the nodes compared to the anti-nodes. The speaker was controlled with a phone app that could play certain frequencies or play a sweep over a specified period of time. This allowed us to quickly experiment with various frequencies and rates of sweeping until we were able to get visually interesting laser projections.

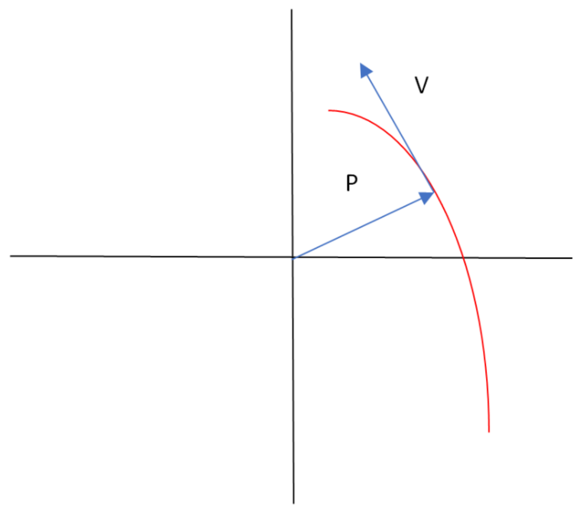
Experimental Setup and Calculations

The experimental setup consisted of a laser which was held in a microphone stand and was directed at a glass Tupperware with a plastic grocery bag rubber banded tightly over the opening. A small circular mirror was taped to the middle of the membrane, and a Bluetooth speaker cone was positioned right behind the membrane. The angle and position of the membrane was such that it projected the laser onto a black posterboard that was leaning against a wall 6 feet away. We recorded video on a phone camera because they could record up to 60 FPS whereas the DSLR's we had with us had a maximum frame rate of 24 FPS. The frequencies that we used were typically in the range of 40-70 Hz, so the higher frame rate allowed us to capture smaller sections of the lasers path throughout the motion.



The projection can be analyzed to tell us information about the sound wave being played such as the frequency, amplitude (volume), and the rate of change of the frequency. A few assumptions can be made for the sake of this report as we don't know all the mechanical properties of the plastic membrane, and the effect of the mirror on the membrane. We will assume the speed of sound through the membrane is the same as through air, and that the mirror is of negligible weight and the rigidity of the mirror does not affect the nodes in the membrane. The outer diameter of the membrane is 5 inches, so that will be the characteristic length used in the following calculations.

If a grid is overlayed on the laser projection, the distance from the origin gives us information as to the change in angle of the mirror from its neutral resting position. The velocity of the laser projection also tells us the rate of change in the nodes in the membrane as the frequency is swept through a range. Below is a figure showing the position vector and the velocity vector of the laser for a given point in time. The reason the projection is not a single point is due to the exposure of the camera and the high velocity of the projection, but we can use this in our favor to find the direction of velocity of the projection at a given time as it is simply tangent to that point.



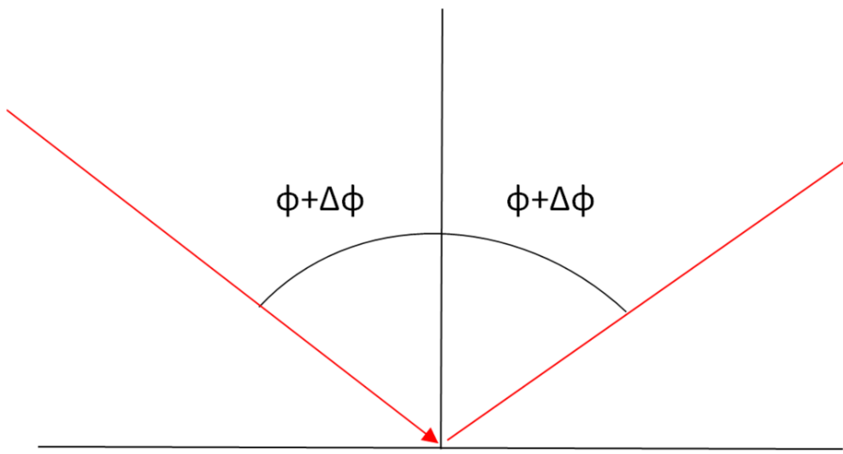
The x and y positions of the laser projection are related to the change in angle of the mirror as mentioned earlier. Because of this, if we take the derivative of the wave equation for a circular drumhead, we can find the position vector given we have information on the distance the projection is from the mirror.

The wave equation for a circular drumhead is:

$$\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial f}{\partial r}+\frac{1}{r^2}\frac{\partial^2 f}{\partial \varphi^2}=\frac{1}{c^2}\frac{\partial^2 f}{\partial t^2}$$

Where f is force, φ is the angle of an axis through the origin, r is the radius of the drum, t is time, and c is the wave velocity.

Note: any change in φ of the mirror is doubled because the incident and reflected ray both change by Δ φ.



Solving the partial differential equation and relating that to the position will be an exercise left for the reader.

Visual Technique

For the experiment I submitted, the frequencies were 46 Hz layered sweep from 15-100 Hz. The laser projection was simply filmed by hand with a phone as there was no tripod or mounting available for the phone, and there was no concern about motion blur as any motion in the phone was negligible relative to the motion of the laser. Since we used a red laser on a black background, there was a lot of contrast for the camera to capture which meant the lighting in the room was not important and the video didn't require any post processing. All the lighting came from the overhead lights in the room at normal brightness and there were no special conditions for the black poster board. The dynamics of the laser cymatics did change throughout the experiment based on volume and frequency, so the camera was framed such that it would capture all the motion from the laser through the experiment. The size of the projection could be changed by moving the mirror closer or further from the poster board, but we found the distance we had set worked well and resulted in a projection that was large enough to see and film.

Photographing Technique

The video was recorded on an iPhone at 60 FPS at a resolution of 1920 x 1080, which is full HD. The camera was held 1.5 feet from the black poster board, which allowed the field of view to capture the full motion of the laser. The camera wasn't zoomed in at all to allow for maximum resolution and field of view in the case the phone didn't have optical zoom. All video settings were automatically set by the camera.

Findings

The image reveals another interesting property of vibrating plates, which in this case was a circular membrane. Often, people are familiar with Chladni plates, but by making a slight change to the experimental setup, another interesting phenomenon is uncovered that is also beautiful. During the experiment, we were talking about how we wished we had a high-speed camera that could film at frame rates in the 1000's of FPS, but in the end the lower frame rate revealed much more because it was clearer to see the path that the laser was taking instead of looking at a single dot move around a black space.

Sources:

"Classical Wave Equations." *Classical Waves*, galileo.phys.virginia.edu/classes/252/Classical_Waves/Classical_Waves.html#Waves%20on%20a%20Circular%20Drumhead. Accessed 5 Dec. 2023.