Wave Machine: A Mechanical Exploration into Tranquillity

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Task:
Design, engineer, realise and demonstrate a device which can show at least one emotion. The emotion(s) should be on/off switchable. The machine should be realised using (mainly) rapid prototyping manufacturing techniques.

Apply:
Exact Kinematic Constraint Design Techniques, Mechanics, Finite Element Analysis, the Lectured Design, Engineering and Manufacturing Content of this Elective

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Introduction

The assignment provided to us was to develop a mechanical system which evokes an emotion. When ideating for this assignment, we landed upon the idea of satisfying automata and wanted to design a mechanical system which emulates a similar emotion, one of satisfaction, or tranquillity. In order to do this, we investigated what could engender these emotions, and we found the motion of waves to be calming and inculcating these emotions within ourselves. Thus began our journey to probe how to realise this motion and emotion in a mechanical system began. We explored using a camshaft and moving a set of “waves”, the individual plates which attach to the camshaft to embody these waves, and therefore emulate waves as a system.

But how does it cause the emotion of tranquillity? The system we have developed uses a camshaft made of medium-density fibreboards to simulate a wave. This is because, according to Erin K [9], a researcher in the field of psychology at the Colby College, accredits this to this “satisfying” sensation to have ties to emotions and stress, where some people find pleasure in autonomous sensory meridian response (ASMR) [6], a perceptual condition wherein audio-visual triggers result in “intense, pleasurable, tingling sensations” in one's head and neck, which could spread to the rest of the body. The emotion that was intended to be exhibited with this project is the emotion of tranquillity. This is because the wave motion causing a calming sensation in people due to the repeating cycle of motion. This repetitive cycle, which has aesthetic appeal according to the authors, has hedonic [7] [5] appeal due to the looks of it being quite mesmerising to look at, but could also result in more eudaimonic [3] [8] thought processes, which together improves one's mood [2] [10]. This is due to the perception of a wave motion being perceived as satisfying. It could be said that this satisfying feeling could be because repeating rhythmic patterns of light and sound, or visuals in this case, can result in entrainment. Human brains look for patterns, and this consistent rhythm results in a satisfying feeling as a result.

These were designed with ease of manufacturability in mind, due to the limited time provided in this course, with the possible need to troubleshoot, and the possible need to remake certain parts.

Process

Design

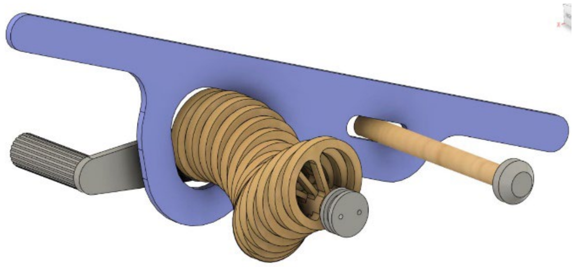

Figure 1: The camshaft integrated into the design.

For the individual waves to be transformed, a camshaft is used. The cams are individually connected to two rods. This decision was made to contain the cams preventing them from rotating. The rods are connected to a plastic bearing which, on one end, is attached to a crank. The crank allows for the cams to rotate transforming the wave. The waves are also attached to a static rod which guides them in their movement.

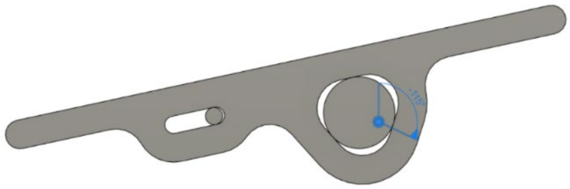

Figure 2: 2D simulation of the camshaft moving the wave.

The contact points from the disk to the wave are minimized to 3, which enables movement in all directions yet minimises the surface area connecting the pieces. The disk is fitted so that it touches all three points at once in order to prevent play from occurring in the design.

Figure 3: Shape optimisation performed on the cams.

For the design of the cams, a finite element analysis was performed to optimise the shape. From this study, it was concluded that the design must include a central beam and be reinforced around the holes. For the aesthetics of the prototype, the design is generalized and further reinforced around the outer edge.

Concerning the rods used to secure the cams, stress tests were executed to determine which materials available were safe to use. To the rods of 120mm, a force of 0.83 Newton was applied. This value was acquired with the following equation:

$$F_z = m * g = \left(\frac{18 * 4.717}{1000}\right) * 9.81 = 0$$

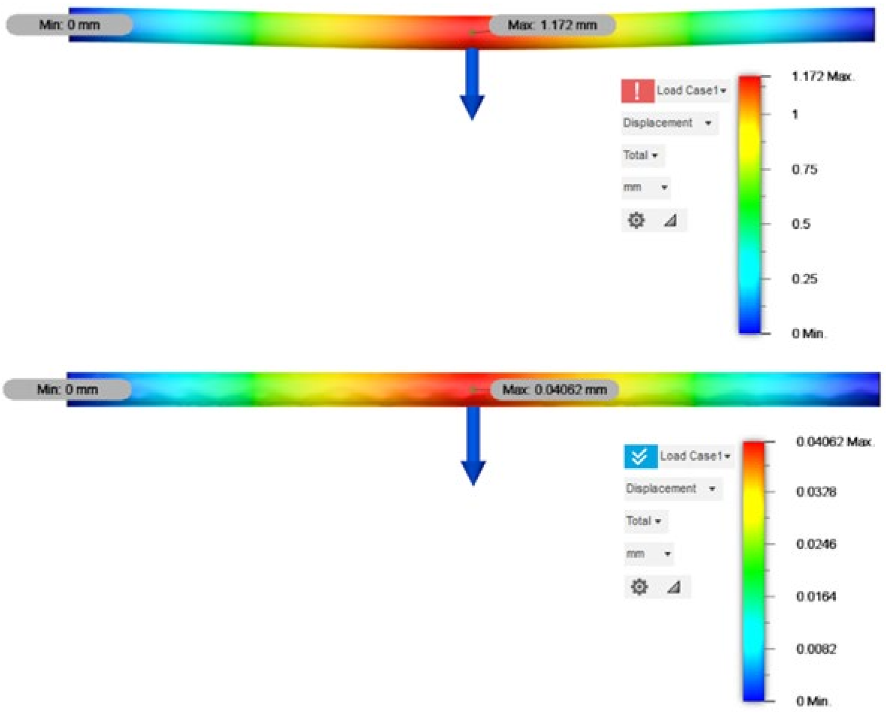

Figure 4-5: Stress simulations on rods.

Testing these forces on both rods it came clear the better option would be to use aluminium rods.

Constraints

This design made use of exact constraints as much as possible. Each wave is designed with a triangular hole in it to fit in the cams of the camshaft, with theoretically no space between them, so as to move optimally. However, due to material burnt away from laser cutting, there exists some space, resulting in play. Thus, when the cams were interacting with the wave, there were at least 2, and at most 3, points of contact, allowing for the rotational degree of freedom in the camshaft to translate to translational and rotational movement in the wave. This is because the wave, while being in contact with the cams, is also in contact with the rod at the back, restricting the degrees of rotation, and thus acting as an anchor.

The rod at the back was designed to only allow for translational motion in one direction for each wave element, as there are constraints such that there are 2 points of contact at the top and bottom of the rod where it comes in contact with the wave elements, restricting any translation in other direction.

Materials

The selection of appropriate materials is a critical aspect of prototype development. In our design, most of the components were made using medium-density fibreboard (MDF) wood, while certain parts were 3D printed using polylactic acid (PLA).

Advantages of MDF:

One of the key advantages of choosing MDF as the primary material for our prototype is its economic value. MDF is widely known for its cost-effectiveness and affordability, making it widely accessible. By using MDF, we were able to keep the overall production costs low.

Additionally, the desired shapes we intended to create using MDF were mostly two-dimensional. Laser cutting was decided as the most suitable method for physically creating these shapes due to its precision and accuracy. With laser cutting, we were able to achieve accurate components, making sure little play or deviation in the shape of the moving parts of the prototype. This level of precision was important, as any inconsistencies in the moving parts could lead to the machine being unable to work.

While designing the parts, we also considered the possibility of inconsistencies in the manufacturing process. To decrease the risks associated with shape variations, we used force-closure contact points between the moving parts rather than relying on form-closure. This approach ensured that the prototype's movements would not be affected by any potential deviations in the material.

An additional advantage of MDF is its smooth surface. This smoothness was beneficial in reducing friction between all the moving parts of the prototype. This would result in smoother operation and minimise wear and tear.

Furthermore, MDF's ability to be drilled and cut without damage was also an advantage for our project. Because of that, we could make alterations to the laser-cut parts as needed.

Another notable advantage of MDF is that it is environmentally friendlier than using wood. It is manufactured from recycled wood products. This makes it a sustainable choice.

However, acknowledging the disadvantages associated with MDF is also important. The material's high density posed a challenge when it came to sanding parts that needed to be changed. The density made the sanding process more labour-intensive and time-consuming.

Another drawback of MDF is its visual appearance. When laser-cut, the edges of the parts tend to get burned, leaving behind black marks that detract from the overall aesthetic appeal of the machine. We addressed this issue by implementing additional finishing techniques like sanding to improve the appearance of the laser-cut parts.

Additionally, MDF is heavier than solid wood, which can have implications for the overall mass of the prototype. The increased mass may contribute to lower eigenfrequencies, potentially affecting the system's stability and performance. To address this, we conducted finite element analysis, as mentioned before, to identify areas where mass reduction was possible without compromising structural integrity.

PLA:

The parts that required complex, doubly curved surfaces were produced using FDM methods with PLA. FDM was chosen because it is easy to create these complex geometrical pieces. Other methods would be more challenging and time-consuming.

We were aware that FDM processes have limitations when it comes to dimensional tolerances. However, since the PLA-printed parts in our prototype were small connection pieces that didn't bear significant force, the weak structural integrity of FDM was not a significant concern.

For pieces that needed to withstand greater force loads, we tested them and redesigned them to ensure they could bear the required forces. The ability to rapidly produce and test these stronger pieces at a relatively low cost enabled us to refine the design and enhance its structural integrity.

In short, the choice of materials for our prototype, MDF and PLA, was based on their respective advantages in specific applications. MDF is cheap and has precise cutting capabilities for creating two-dimensional shapes, giving us minimal play in the moving parts.

FDM printing offered the ability to produce complex, doubly curved surfaces cheaply and fast. While dimensional tolerances had to be carefully considered, the strength requirements for smaller connection pieces were met, and iterative testing allowed us to optimise the design for the specifying force loads.

Manufacturing Processes

Laser Cutting

The main manufacturing process used to create the prototype was laser cutting [1]. Due to the need to create multiple identical parts for the disks and the waves, we had to choose a manufacturing process that ensured accuracy. Laser cutting works by focusing a beam of monochromatic light on the surface intended to be shaped, causing it to create plasma and melt to create the shape needed. Laser cutting was also a good manufacturing choice given that the material used, MDF, is a composite material and laser cutting allows for cutting heterogeneous materials. Due to the fumes that laser cutting generates and the safety precautions it requires, the team did not handle the laser cutting themselves, instead having an expert at the university handle that process. Laser cutting was also used for the frame of the prototype since the sides and bottom of the frame needed to fit together properly. This manufacturing method allowed for a perfect fit.

3D printing

3D printing [1] was done to create small pieces needed to fasten the laser-cut parts together. These pieces needed to be precisely made to ensure a correct fit and for them to seamlessly blend into the rest of the prototype to ensure an aesthetic prototype. 3D printing with PLA was done using the Ender 3v2 3D printer. This machine works by depositing the PLA through a multi-jet print head, layer by layer, to create the required shape. 3D printing is a beneficial manufacturing process since it is accurate and quick, in comparison to more conventional manufacturing processes. However, it is necessary to design the pieces properly. Initially, when the pieces fastening the beams holding the disks in place were designed, they were made too thin which caused them to snap once the wave was cranked.

Adhesive Bonding

Even though laser cutting allowed for the shapes to fit together like puzzle pieces, we decided to use adhesive bonding [1] [4], in the means of wood glue, to ensure that the pieces would stay together when put under stress while the user turned the wave. Wood glue is a polyurethane flexible adhesive specially designed to adhere wood pieces together and have good resistance. The wood glue used in our project has a temperature resistance of 60 degrees Celsius.

Friction

The 3D pieces created to fasten parts of the project together act as snap fits. They involve no heat and are easy to disassemble. They hold the pieces together thanks to the friction created between the 3D pieces and the MDF. We chose such a manufacturing process for the fastening of the MDF pieces since we required a large elastic deflection for assembly and disassembly.

Coating and Deposition Processes

To ensure a smooth movement of the pieces, all the MDF waves were coated in a petroleum-based lubricant to reduce friction.

Discussion

As seen in Figure 1, the outer waves are not properly constrained, causing them to occasionally fall out. This design flaw could be prevented by extending the diameter of the interior of the bearing, covering the outer cam and wave element.

One of the obstacles discovered during the manufacturing was that the individual waves applied more friction on one another than anticipated. As earlier mentioned, the issue was solved by the application of a petroleum-based lubricant. However, this issue could have been prevented in the earlier stages of the design process. A possible solution would have been to space the wave elements further apart, eliminating all friction between the individual waves.

When looking at the different types of designs, we conclude that the prototype we made is an example of Design for Manufacturability. This is because the pieces required to manufacture such a product are easy to manufacture and repetitive. The product requires lots of identical parts therefore producing it in bulk is achievable. Furthermore, if we had created the wave shape from a singular structure instead of multiple individual components, it would better fit into Design for Assembly as it would make it quicker and easier to assemble. When looking into the reparability of the product, we see that all pieces are removable and replaceable. However, the device is not extremely durable and could break if extreme force is applied. Thanks to the product being mainly made out of MDF, which is constructed using wood fibres and other portions which normally would go to waste, the design can be considered environmentally conscious. Laser cutting as a manufacturing process can also be considered environmentally friendly since it facilitates recycling.

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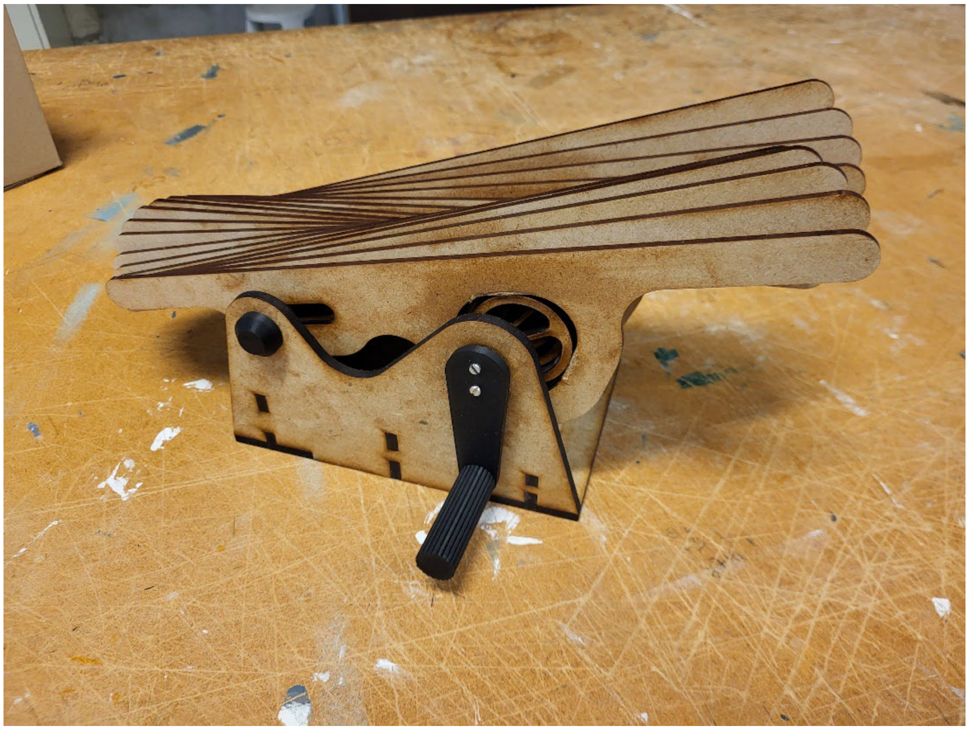
Appendix



Appendix 1-3: Pictures of the complete wave machine