CONSTRUCTING A TENSEGRITY TABLE

ME206, Experiment 1

Abstract

This experiment is based on the structure of a tensegrity table, which is an unusual structure to comprehend, owing to its unintuitive construction.

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Introduction

Tensegrity structures are a very unique and ingenious type of engineering or architectural constructions. They rely on balance between the elements experiencing tension and compression to maintain their stability and form. The word 'tensegrity' is derived from a combination of two words, 'tensional integrity'. This in essence is a condensed form of a tensegrity structure's core principle – stabilisation and definition of shape by the tensioned elements while the compressive elements are disconnected from each other.

The tension elements in tensegrity structures are usually in the form of wires, cables, tendons, etc. These elements are constantly under tension, and this tension is responsible for holding the entire structure together. In the construction of a tensegrity structure, the elements are typically arranged in a network of interconnected lines. Along with the tension elements, the tensegrity structure also has rigid bars, rods or struts which act as the compression elements. These compression elements push against the tension, while they are being rigidly held in place.

The Spodek arena, Katowice, Poland [1]

The Super Ball Bot [2]

Tensegrity structures are incredibly versatile, and hence they have a great number of applications in a large number of fields. For example, the Spodek arena complex in Katowice is one of the first major and large-scale structures to employ the principle of tensegrity within its design. One of the more famous applications of tensegrity is the Super Ball Bot, a rover for space exploration which utilises a 6-bar tensegrity structure, currently in development at NASA.

The balance of forces in a tensegrity structure gives rise to their remarkable properties, like:

1. **Efficiency and lightweightness:** The materials used to construct a tensegrity structure are minimal, achieving stability more efficiently.
2. **Adaptability:** Using force distribution to maintain equilibrium, tensegrity structures can adapt to external loads.
3. **Collapsibility:** The tensegrity structure can expand, retract or change its shape, since its tension elements can be adjusted.

Tensegrity table: A tensegrity table is a tensegrity structure which acts as a regular table. Objects can be placed on top of it like a regular table. It is an object which serves as an elegant alternative to regular and standard table furniture.

The Experiment

AIM

To construct a tensegrity table with a maximum load bearing capacity of 3 kg, and quantify the values of tensions for loads up to 3 kg and also find the frequency of torsional oscillations for the same range of loads.

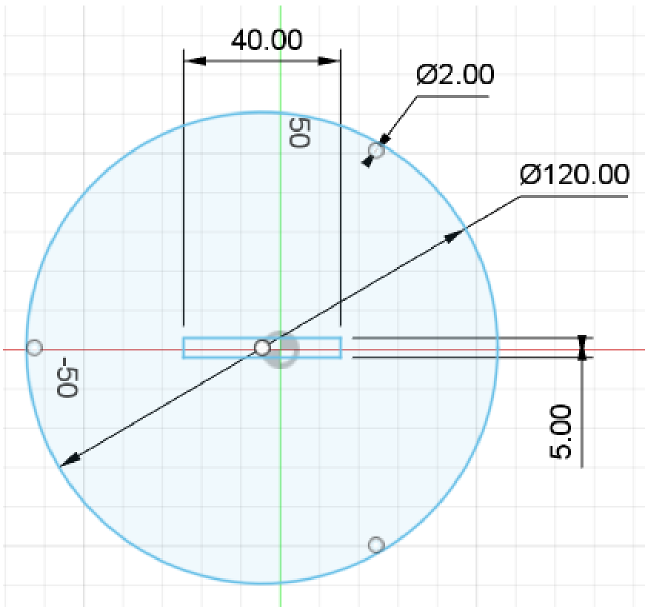
This experiment will comprise of two parts:

1. **The Theoretical Part:** This part shall comprise all the theoretical calculations related to this experiment, like realising the theoretical model of the tensegrity table. This part shall utilise a lot of core concepts from the field of statics, such as free-body diagrams and static equilibrium.
2. **The Practical Part:** This part shall comprise the more physical aspects of this experiment, such as making the tensegrity table itself and measuring the values of tensions and the frequencies of torsional oscillations for loads up to 3 kg.

After executing both the parts of this experiment, the results from each part need to be compared meticulously in order to identify similarities and differences, and think about reasons as to why those similarities and differences exist.

EXPERIMENTAL DESIGN

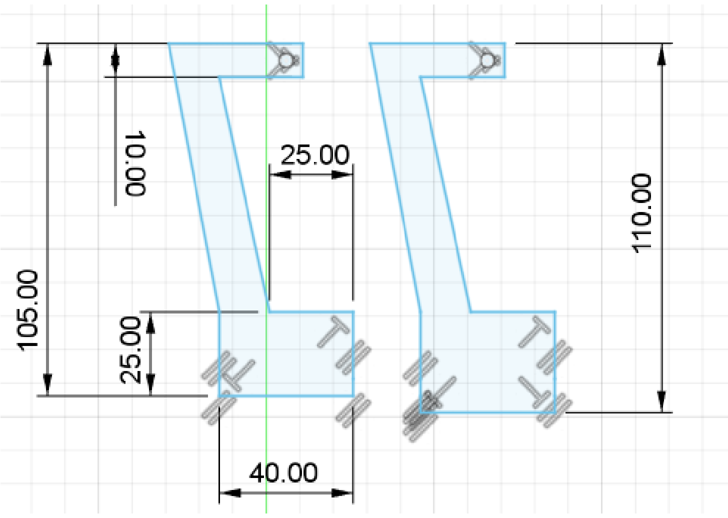
Below are the images of the CAD model of the parts constructed in Autodesk's Fusion360 software:



This image shows the design of the discs which make up the top and bottom parts of the tensegrity table. The disc is 5 mm thick, and has a 40 mm × 5 mm rectangular slit in the centre to accommodate the vertical arms. The disc also has three holes of 2mm diameter each at the edge, and these centres of these holes form the vertices of an equilateral triangle. These holes exist to anchor the strings which connect the top and bottom parts of the table. Two discs together form the base and one singular disc forms the top.

This image shows the design of the discs two vertical arms which form a part of the central support structure of the tensegrity table. The hole at the narrow part of each arm is 2 mm in diameter.

The dimensions of both the arms are exactly the same barring the height. One of the arms is 5 mm longer at the base. The thickness of both the arms is 5 mm.



ENGINEERING DRAWINGS OF PARTS

MATERIAL DATA

To construct the tensegrity table, we carefully thought about what materials to use, since the table needed to be light and strong at the same time. We found that MDF sheets would be the optimal material to construct our table with, since its strength to weight ratio is quite high. Also, since our experiment required our tensegrity table to be able to bear a maximum load of 3 kg, 5 mm thick MDF would be a perfect fit since it can easily handle loads of that order of magnitude. For the strings which would be under tension and hold the structure together, we decided to use plastic twine, since it was easily available and also very strong compared to our needs.

Here is the full list of materials we used to make our final tensegrity table model:

- 390.12 cm^2 of 5 mm thick MDF
- Approximately 55 cm of plastic twine
- Cyanoacrylate adhesive (to secure the arms to the base and top)

FABRICATION DETAILS

The fabrication of the tensegrity table was carried out in a very meticulous manner:

- First, the top and bottom circular bases and the two central prongs of the structure were designed on Autodesk's Fusion360 modelling software.
- Next, the files were exported as .dxf files so that they could be accessed by Trocen's LaserCAD software.
- The .dxf files of the design were loaded into the laser-cutting machine, which cut the MDF sheet we possessed into the shapes required for our table.
- Two of the discs obtained were glued together along with one of the vertical prongs to create the base of the structure.
- The third disc and the second vertical prong were glued together to create the top of the structure.
- Plastic twine was attached to base and the top and the two halves of the structure were assembled together to form the complete tensegrity table.

THEORETICAL ANALYSIS OF A TENSEGRITY TABLE

The completed tensegrity table.

This was made using MDF, plastic twine, and a lot of careful thinking and hard work by everyone!

MEASUREMENT TECHNIQUES USED

To measure the frequency of oscillations:

- The frequency of torsional oscillations was measured by recording slow-motion footage of the oscillating tensegrity table.
- The table was disturbed from its position and slow-motion video of it oscillating was captured for a fixed interval of time.
- The video was then played back and the number of oscillations was counted manually, which was then divided by the time of the video to obtain the frequency of torsional oscillations.
- This was done for every load up to 3 kg. Each recording was done with an increment of the load from the previous iteration.

$$f_{Torsional} = \frac{n_{oscillations}}{T}$$

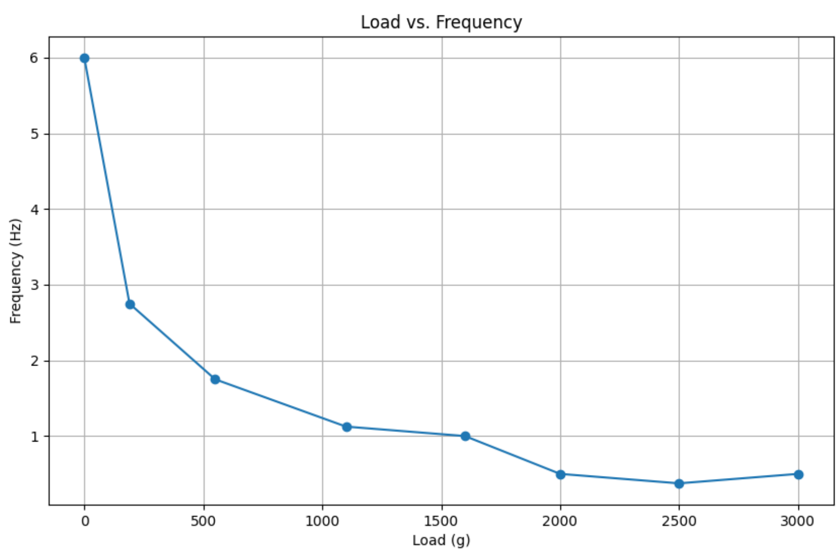
RESULTS

Torsional Oscillations in the tensegrity table:

Torsion Angle = 19°

Sr. No.	Load	Frequency of Torsional Oscillations
1	0 g	6 Hz
2	190 g	2.75 Hz
3	550 g	1.75 Hz
4	1100 g	1.125 Hz
5	1600 g	1 Hz
6	2000 g	0.5 Hz
7	2500 g	0.375 Hz
8	3000 g	0.5 Hz

Using the values from the above table, the following graph was obtained:



DISCUSSION

In the aftermath of the tensegrity table experiment targeting a 3kg maximum load capacity, notable insights have arisen. The experiment highlighted the delicate balance within tensegrity structures and the need for precise materials and engineering for optimal performance. While successful in achieving the load goal, the experiment emphasized the intricate interplay between design, materials, and forces, suggesting potential avenues for enhancing load-bearing capabilities.

Throughout the experiment, challenges emerged in aligning tension cables and compression members for load sustainability. Iterative adjustments to cable tension and compression elements were pivotal. These insights provide a foundation for future tensegrity designs, where advancements in materials and engineering could potentially increase load capacities. As tensegrity structures continue to captivate researchers, this experiment contributes to innovation at the intersection of art and engineering.

From the values of the table and the graph in the results section, we see that as the load on top of the tensegrity structure increases, the frequency of torsional oscillations decreases. This may be because of a shift in the system's equilibrium and mechanical properties. The increasing loads increases the compressive forces in the structure, which causes the compressive forces to slightly buckle deforming the overall shape of the structure. The increased compressive forces also increase the stiffness of the structure, which results in a slower rate of rotation during oscillations.

SHORTCOMINGS

During the course of conducting this experiment, we faced various challenges and also had takeaways from them.

One major shortcoming was the absence of a system to measure the tension in the strings holding the entire structure of the tensegrity table together. We devised a method which involved suspending a spring between two parts of the strings and then measuring the extension in the spring for different loads, and then using those values of extensions we could calculate the corresponding values of the tensions in the string. However, while implementing this system, we found that trying to attach a spring between two pieces of string destabilises the entire tensegrity table, resulting in it not being able to support a significant load. Hence, we decided to forego these measurements due to the time constraint given to us and also in favour of the structure's stability.

Since we were unable to measure the tensions in the strings holding the structure together, we were unfortunately unable to draw a comparison between the theoretical calculations and the practical results of the experiment, which was a really important and interesting component to analyse.

There were also a few minor shortcomings, such as the size of the top and bottom discs was not large enough to balance weights on top, and this was only realised by us when we completed the construction of the structure, and also, the top part had to be laser-cut again since the top arm was attached to the top disc in the opposite direction due to which the holes of the top and bottom discs did not align.

POSSIBLE IMPROVEMENTS

There are many improvements which can be made to the existing structure of the tensegrity table discussed in this report, such as:

1. **Material Upgrade:** Consider lightweight composites like carbon fibre to strengthen the table while reducing weight, boosting load-bearing capabilities.
2. **Enhanced Tension Elements:** Explore stronger cables or wires for better stability and load distribution within the tensegrity structure.
3. **Reinforced Joints:** Add metal brackets or custom connectors to strengthen joints between prongs and bases for increased stability.
4. **Advanced Adhesives:** Experiment with epoxy or structural adhesives to ensure a more durable and robust assembly.
5. **Structural Analysis:** Perform finite element analysis to identify weak points and optimize stress distribution for improved overall performance.
6. **Optimized Design:** Refine design elements to reduce stress concentrations and enhance load distribution, considering variations in geometry.
7. **Experimental Iteration:** Test different material thicknesses, tension levels, and joint configurations to determine optimal parameters for load-bearing capacity.

Attempting all of these improvements to the original structure would be unviable and expensive, but by considering some of these potential improvements, the tensegrity table's strength, stability, and load-bearing capacity could be enhanced, pushing the boundaries of its structural performance and offering valuable insights for future tensegrity designs.

References

[1] Katowice-Spodek [Online]. Available:
https://commons.wikimedia.org/wiki/File:Katowice-Spodek_(8).jpg

[2] NASA SUPERball Tensegrity Lander Prototype [Online]. Available:
https://en.wikipedia.org/wiki/File:NASA_SUPERball_Tensegrity_Lander_Prototype.jpg

Prof. K.R. Jayaprakash's lecture slides for the course ME206: Statics and Dynamics

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