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PROJECT CHARTER: MANUFACTURING A SPIROMETER

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ABSTRACT

A Spirometer is a device typically used to measure the lung capacity of a person. In this project, we have designed a mechanical spirometer using Autodesk Fusion, manufactured it using additive and subtractive manufacturing, and used an Arduino circuit and the lm393 rotary sensor to measure the lung capacity. Air is blown on the impeller's blades, which results in its rotation, in turn rotating a slotted disc using a shaft and bearing mechanism. The lm393 sensor then measures the number of times the disc rotates in a minute which is reported using the Arduino circuit.

Keywords: Spirometer, Lung Capacity, lm393 rotary sensor, impeller, Arduino, additive manufacturing, subtractive manufacturing.

NOMENCLATURE

η number of holes
θ number of times light is obstructed in a second

1. INTRODUCTION

The peak of the COVID-19 pandemic witnessed an unprecedented need in the market for devices monitoring respiratory health. One of the most common devices for this purpose is the Spirometer. A Spirometer is a device used to measure lung capacity: additive manufacturing or 3D printing in constructing a three-dimensional object using a CAD model or CAD drawing. Similarly, subtractive manufacturing is the material removal process to obtain the desired design.

The Spirometer consists of an impeller, a slotted disc, shaft, and bearing mechanism, placed in a housing. The impeller has been created using 3D printing technology, while the housing and slotted disc have been created using laser cutting.

2. DESIGN

Our design philosophy was centered around the famous "*Function over form*" ideology. We had to work under the size constraints set by the problem statement while also accommodating that the model fulfills its purpose. In addition to this, it was essential not to make anything very complicated that would be problematic to manufacture. Hence, keeping the above constraints in mind, we worked around our prototype.

2.1 Initial Approach

The process involved scaling the image shown in the guideline document. We followed a top-down approach by first drawing rough sketches of the base plate and eliminating the space to be occupied by the already given standard elements like the breadboard and the rotary sensor. This gave us an idea of how much space is left for us to fit in the housing and the slotted disk. Moving further, we eliminated some space on the sides of the breadboard to ensure the model looks spacious enough and not congested. This gave us a rough idea of the size of the housing.

2.2 Housing

The problem statement dictated that the entire model should fit in a 120 mm (L) X 70 mm (W) X 50 mm (H) box; hence, we decided to take the height of the housing to be 50 mm and then made the length to be 65 mm while width to be 40 mm. We chose the housing sheets made of an MDF board with 5 mm thickness and made one side of the housing using an acrylic sheet for aesthetic purposes. As explained later, one of the housing faces was also manufactured using 3D printing for "friction-fit" purposes.

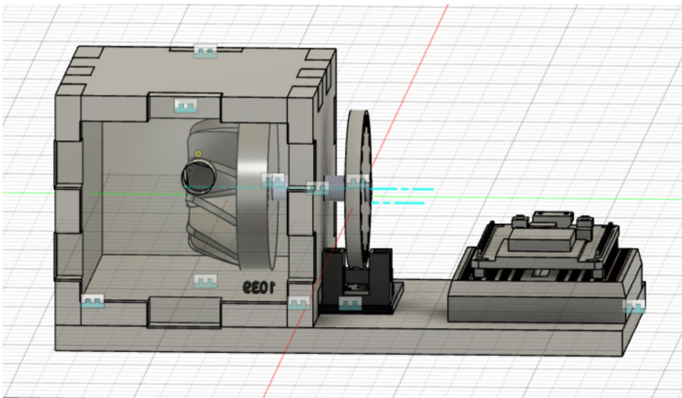

FIGURE 1: CAD MODEL OF THE FINAL ASSEMBLY

2.3 Slotted Disk

The dimensions of the slotted disk were scaled using the housing. We had already decided that we would fix the shaft and bearing in the middle of the housing face and hence scaled the distance between the center of the housing and the slot between the rotary sensor. This gave us the radius of the disc. The number of slots was determined by trial and error, ensuring they were well spaced and optimal in size. A slot was also left in the center of the disk to fit the shaft.

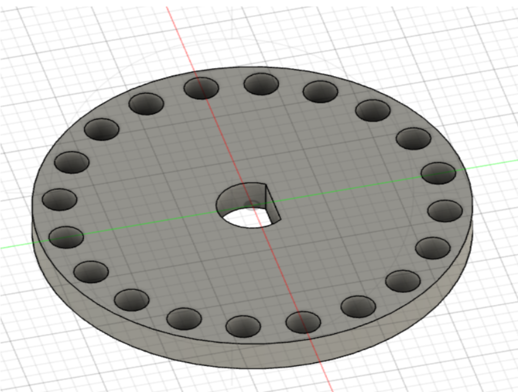

FIGURE 2: CAD MODEL OF THE SLOTTED DISK

2.4 Impeller

The impeller is one of the essential components of this spirometer. While designing the impeller, it was essential to ensure adequate spacing from the edge of the housing. Hence, the height of the impeller was 20mm. It was also crucial to not make it very bulky such that moving it by blowing air would not require a large amount of force. We thus made this impeller of 32 mm diameter. In addition to this, the impeller's blades were of 1.4 mm thickness such that they are strong enough. And it was essential to give a slot at the base of the impeller to fit in the shaft. Hence keeping all this in mind, we designed a semi-open impeller with a flat base at one side to ensure stability while 3-D printing with a slot for the shaft. The number of blades was made to be ten and decided based on numerous resources available on the internet that allowed us to scale our model similar to other real-world models.

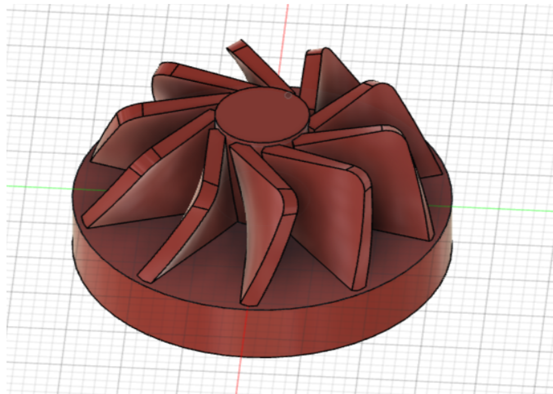

FIGURE 3: CAD MODEL OF THE IMPELLER

2.4 Friction fit, stability, and kerf

Another factor that we kept in mind was to ensure "friction fit." We provided that all the components would naturally friction fit into each other. Thus all the components should have dedicated slots for the same. Both the impeller and slotted disk had to be fit on the shaft and bearing. We, therefore, fit the bearing in one of the faces of the housing, for which we created a concentric circle-like pattern that fits both shafts and bearing individually, as shown in the image below. This was a unique design, and it was difficult to laser cut it as directed in the initial guidelines. Hence, we made a special request to 3D print this face. This ensured that the shaft and bearing were fit in snuggly and the model was stable. Secondly, we accounted for the kerf of laser cutting in the slotted disc and housing. According to our expectations, the result was minimal filing and need for adhesives during assembly

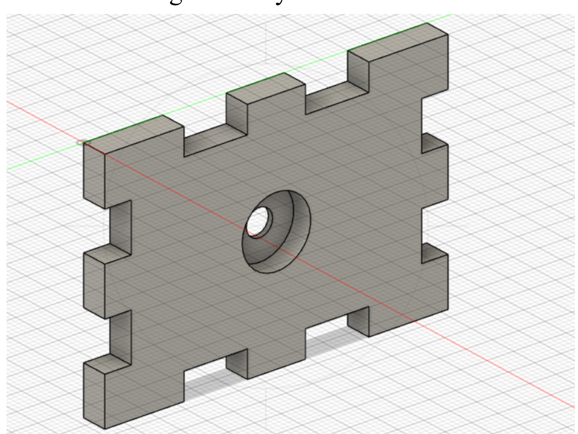

FIGURE 4: CAD MODEL SHOWING CONCENTRIC HOLES TO FIT SHAFT AND BEARING IN HOUSING FACE.

3. MATERIALS AND METHODS

The primary technology used for manufacturing was Laser cutting and 3D printing. While the materials used were acrylic sheets, MDF sheets, and PLA plastic.

3.1 3D printing

3D printing is an additive manufacturing process that uses a computer-aided design to create a 3D object layer by layer. The technology involves converting. CAD models to .stl files are stereolithography files that divide the structure into smaller triangular pieces joined together. These .stl files are then converted into G Codes, which are codes that direct the movement of the printer. The impeller and one of the faces of the housing were created using this technology. The material used was red PLA or polylactic acid, liquid at high temperatures and solidifies on cooling.

3.2 Laser cutting

Laser cutting is a technique used to perform subtractive manufacturing. It involves cutting operations using a laser beam. The laser beam burns away the material, thus cutting. Laser cutting consists of converting 3D CAD models to 2D .dxf files, further converted in G Codes, and fed into the cutter. The G Codes then direct the Laser cutter about where to perform cutting operations. Laser cutting can be done on several different materials involving wood, plastic, etc. One of the primary factors to keep in mind for laser cutting is the kerf, which is the additional material cut by a laser cutter. The kerf usually is in the range of 0.15-0.2 mm. While designing components, it is essential to account for this kerf.
In our project, we have utilized 5mm MDF boards and 5 mm acrylic sheets for housing. One of the faces of the housing was created using transparent acrylic sheets for aesthetic purposes. The slotted disc was also manufactured using laser cutting.

4. ALGORITHMS

- The sensor is connected to pin 13 on the Arduino board.
- The baud rate of exchange is 9600 bits per second set
- An infinite loop is created in which the time is set to 1000 milliseconds equal to one minute.[1]
- The number of times light passes after being obstructed is detected by the sensor and passed to the Arduino board, increasing the “step” variable by one.
- These steps are then divided by the number of holes to calculate the rotation per second(RPS) multiplied by 60 to obtain rotation per minute(RPM).

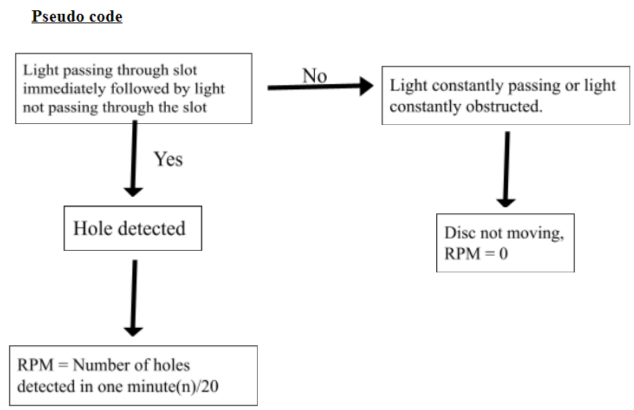

FIGURE 5: FLOWCHART SHOWING THE CIRCUIT LOGIC

5. RESULTS AND DISCUSSION

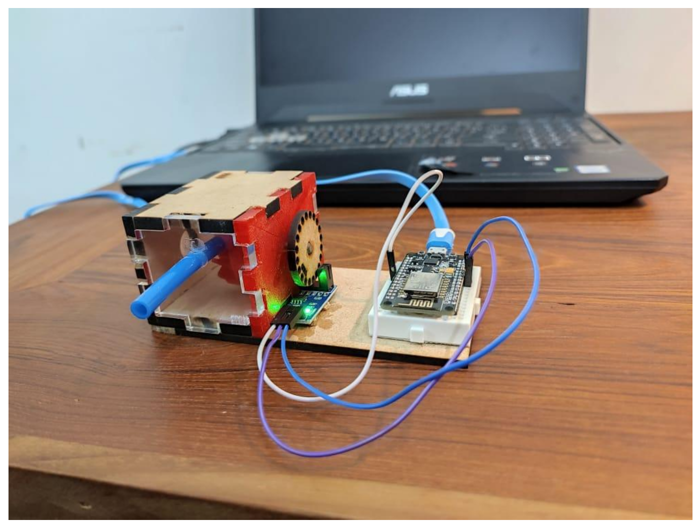

FIGURE 6: FINAL ASSEMBLED MODEL AND CIRCUIT(*size can be scaled using laptop at the back)*

5.1 RPM speed

The number of rotations per minute will be the number of times light is obstructed in a minute multiplied by 60 seconds and divided by the number of holes in the slotted disk.

$$\text{RPM}= \frac{\theta*60}{\eta} \tag{1}$$

$$\text{RPM}= \frac{\theta*60}{20}$$

$$\text{RPM}= 3\theta$$

5.2 Lung Capacity

The following values were obtained while varying the amount of air blown through the blowpipe into the Spirometer.

RPM	Lung Capacity
<360	Below Average
360-780	Average
>780	Good

TABLE 1: LUNG CAPACITY BASED ON RPM *(This was concluded after surveying on a very small dataset and is subject to change based on user group)*

6. CHALLENGES AND FAILURES

The scaling and dimensioning of the model were difficult since we only had one reference image. Many rounds of hit and trial were required in order to reach a practical and efficient design. Secondly, having little to no knowledge about practical aspects of 3D printing and laser cutting, we struggled with accounting for the errors that would be there in both processes. In the final model, we had to file components like the impeller due to errors in manufacturing. Initially, we had added a cylindrical slot in the base of the impeller to fit in the shaft. However, later we learned that this would create issues in 3D printing, and hence, we modified our designs at the last moment to accommodate this.

7. RECOMMENDATIONS AND IMPROVEMENTS

In the future, we would like to focus more on the aesthetics of the model. Currently, the circuit in the model is bare, and hence, we would like to create a structure to cover it and the rotary sensor. We would also like to develop overall housing such that only the blowpipe is accessible from the outside. A digital screen can also be fixed on the side to display the RPM. The code can be further modified to display the lung capacity type such that the user does not have to refer to a manual to interpret the numerical values.

8. CONCLUSIONS

Overall this project has been an excellent learning opportunity since it exposed us to hands-on experience of the various manufacturing processes. It allowed us to work on creating scalable and practical models while accounting for errors in the process. We also learned the working and logic of NodeMCU and the usage of Arduino IDEs.

ACKNOWLEDGEMENTS

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REFERENCES

[1]https://www.electronicshub.org/interfacing-lm393-speed-sensor-with-arduino/

CONTRIBUTIONS

Aditi Agarwal(20110006)

Co-planned initial designs and dimensions, designed and scaled the components such as slotted disk and impeller, wrote the model's pseudo-code and actual code, and compiled and documented the project report.

Aishwarya Omar(20110008)

Co-planned initial designs and dimensions, designed and scaled the housing and final assembly, laser-cut mockups for reference, shot the video for model presentation. Assembled the final parts and synced codes to sensors and NodeMCU.