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SPIROMETER

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ABSTRACT

A spirometer is an instrument used to measure the relative breathing capacity of the lungs. The design of the spirometer we have implemented is based on a freely rotating impeller mounted on a shaft which is then placed in a housing block. A person blows air through a pipe fixed in the block, and it exerts some pressure on the wings of the impeller. As a result, the impeller starts rotating, and the frequency of these rotations is recorded as an indirect measure of the lung capacity. Several manufacturing and post-processing processes were executed throughout the project. Firstly, The CAD models for the impeller, Casing, and slotted disk were designed, which further led to the manufacturing part. The impeller was manufactured using PLA by FDM/3D printing, and the Casing was designed with acrylic sheets by Laser cutting. The slotted disk was manufactured the same way. The basic principle applied for measuring the frequency of rotations is to count the variations occurring per minute in the slotted disk's rotating surface, for which an LM-393 Rotary Encoder along with NodeMCU (ESP-8266) was used. The coaxially connected disk starts rotating as the impeller rotates, and the LM-393 sensor detects the slots placed on the disk. After manufacturing, the next step was to assemble all of these parts together and make the NodeMCU compatible with the setup in order to measure the speed of rotations. The overall project emphasizes hands-on learning of the manufacturing processes and designing a wholesome product that meets end demands.

Keywords: PLA (Polylactic acid), FDM (Fused Deposition Modelling), LM-393

1. INTRODUCTION

The conventional spirometers used in medical sciences estimate a direct measure of the breathing capacity of the lungs. They are fixed with volume measuring apparatus that measures the amount of air that is being inhaled or exhaled by the lungs. The true version is concerned with various design and medical-related aspects, and therefore is too complex. However, an alternate model for the spirometer has been designed, manufactured, and implemented for this project.

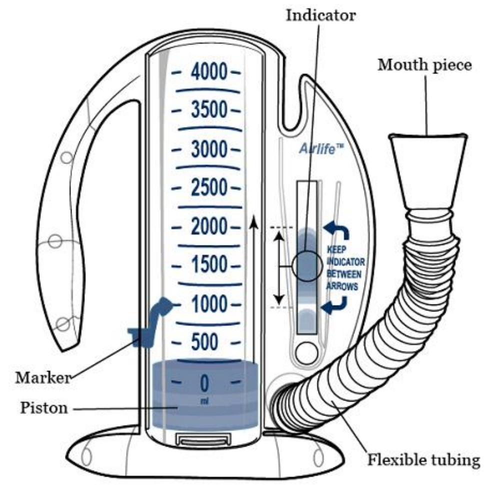

FIGURE 1: AN ORIGINAL INCENTIVE SPIROMETER USED IN MEDICINE

The above-shown spirometer uses a piston-tube arrangement to measure the lung capacity in the form of the height rose by the piston, which in turn gives the pressure and volume of air that is being inhaled and exhaled by a person blowing through it. Similar to this approach, we have used an impeller-disk assembly over a shaft which gives an indirect measure of the lung capacity. When a person blows air, and it hits in between the wings of the impeller, the energy possessed by air is transformed into the Kinetic Energy of the impeller, which in turn makes the slotted disk rotate synchronously with it. The rotations per minute of the slotted disk are measured for the sake of obtaining the final indirect estimate of the lung capacity. There are several kinds of Spirometers being used in the modern-day medical sciences, out of which the proposed one will have comparatively low-cost manufacturing though at the cost of less accuracy.

2. DESIGN

This part included deciding the dimensions for the different components in compliance with the various assembly constraints. firstly, we had to design the model such that the whole system assembly could be placed on an MDF base plate of size 65 x 110 mm. so, we decided to make the complete housing with the dimensions as 50 x 30 x 45 mm. the dimensions of various walls were decided accordingly. plug-in slots accompanied the housing parts to be friction fitted with one another. also, as housing is the part that has an impeller inside it, it should be proximate to the impeller. otherwise, the air may escape, and the full impact of pressure wouldn't be seen on the impeller.

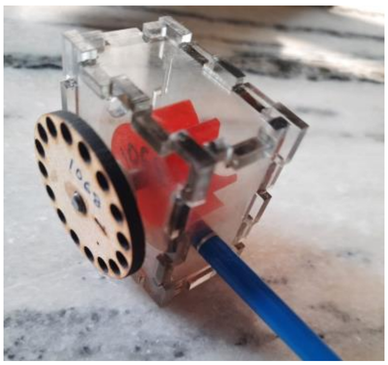

FIGURE 2: THE HOUSING ASSEMBLY

With the current decided dimensions of the housing, a space of around 40 x 20 x 35 mm was available inside the box. Also, it required the impeller to be at least 4 mm away from the housing wall so that it could rotate freely about the axis of the shaft. So, the thickness of the impeller was kept at 15 mm along with a diameter of 25 mm. The wings of the impeller were designed with the minimum possible thickness so that they could be 3D-printed effectively. Then the slotted disk, which had to be placed over the same shaft just outside the housing, was kept in order to rotate freely without any constraint. There was a sensor which has to be kept below the disk such that the slots of the disk completely passed through its terminals, as we can see in figure-3. Accordingly, the dimensions for the disk were designed.

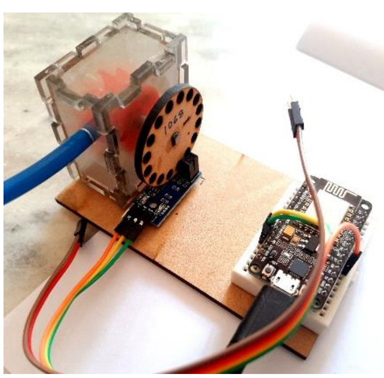

FIGURE 3: THE FULL SYSTEM ASSEMBLY

As it is clearly visible from figure 3, the holes for the blow-pipe and shaft were designed in the housing walls themselves. The dimensions of the available shaft were kept in mind while designing these holes, as well as the slots at the center of the impeller and slotted disk. We also had to incorporate the Laser cutting kerfs for these center holes, as any error in the dimensions of these holes would have created a mishap. Additionally, a small hole was designed at the back wall to ensure a steady flow of air in and out of the block.

3. MATERIALS AND METHODS

Various materials & methods were used for fabricating the components of the spirometer that are as follows:

3.1 MDF

Medium Density Fiberboard (MDF) has been used for making the slotted disk as well as the base plate. MDF is a lightweight, low-cost material which is widely used for fabricating parts through Laser Cutting. MDF is a dense composite material and doesn't produce chips easily, and therefore, it is a perfect choice for machining, drilling or cutting operations

3.2 PLA

Polylactic acid, commonly known as PLA, is a plastic material that is commonly used with FDM for printing different parts. It has been used for fabricating the impeller. PLA is basically a polyester with strong tensile strength and is widely available and cost-effective.

3.3 Acrylic

Acrylic is a transparent plastic material with immense strength and thickness. They are easy to fabricate products with Laser cutting operations. The housing has been fabricated from the 5mm thick acrylic sheets.

3.4 FDM/3D printing

FDM or Fused Decomposition Modelling is a widely used process for printing 3D models. In this process, a thermoplastic material (PLA here) reaches its melting point, and flows out of a nozzle with fixed parameters for creating 3D objects layer by layer.

3.5 Laser Cutting

It is a widely used machining process for producing fine cut edges. The process includes vaporizing the work material through the incidence of lasers on them which produces a fine cut edge in it. The process is controlled by the computer numerical control (or CNC).

4. ALGORITHMS

The overall process comprises of different steps that were taken in order to manufacture our own Spirometer:

- The very first step was to figure out the dimensions of various components that has to be designed.
- Designing the CAD models of different components for fabrication with FDM/Laser cutting.
- Fabricating the parts, and assembling them together.
- Coding the NodeMCU unit in order to read the sensor data and analyze the rotation speed of the impeller.
- A separate computer algorithm that we used for calculating the rotational frequency/speed of the impeller is as follows:
  - We read the binary inputs from the sensor for the presence of either a hole or the surface, and counted the number of slots passing through the sensor terminals.
  - As our slotted disk had 16 holes, it implies that for one full rotation 16 separate holes pass through the terminals of the LM-393 sensor.
  - We calculated the total number of rotations of the disk as:

$$\text{Number of Rotations} = \frac{\text{Number of passed holes}}{16} \quad (1)$$

  - Then, the current RPM (rotations per minute) for the disk were calculated as:

$$\text{RPM} = \frac{\text{Number of rotations}}{60} \quad (2)$$

5. RESULTS AND DISCUSSION

Assembling the fabricated parts, we were also able to better understand the different manufacturing processes and engineering materials used in the project.

The purpose of the model was to determine an indirect measure of the lung capacity. So, we tried to measure it and obtained the following data:

S. No.	RPM
1	0
2	0
3	198
4	562
5	423
6	263
7	41
8	270
9	630
10	558
11	355
12	0
13	210
14	761

TABLE 1: SPIROMETER CONTINUOUS DATA RECORDED FOR AN ADULT (M)

We also tried to observe the pattern of rise and fall of rotations as the person continues to blow on air without a single breath in between.

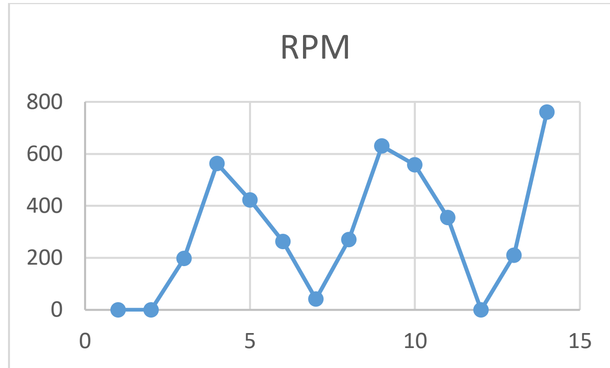

FIGURE 4: VARIATION OF RPM MEASURE OF BREATHING CAPACITY IN ONE GO

From the Graph above, it is clearly visible that the RPM measure of lung capacity for an adult holding his breath as much as possible, keeps on increasing and decreasing according to the pressure exerted on the wings of the impellers. So, we can say that a person who can deliver a long duration of rotations at higher RPMs will have better lung capacity.
For the collected Data, the mean RPM is calculated somewhere close to 305.

6. CHALLENGES AND FAILURES

Initially there was slight error in the dimensions that we chose for the Impeller. We encountered that it was impossible to print an Impeller with the dimensions we decided for it.

There were some challenges in assembling the components as well. One of the housing walls that was supposed to have a hole for the blow-pipe to enter didn’t have it. The wall was redundant with its opposite face. So, somehow, we had to manage a hole in one of the walls.

The impeller slot was a little bit small for the shaft to fit in, but we were able to encounter it with a little amount of lubrication.

7. RECOMMENDATIONS AND IMPROVEMENTS

The kind of output we get at the end can be improved and can be made user-friendly. We could eventually develop a scale for this type of spirometer that we have designed. Maybe, doing some data and statistical study of the device we will be able to differentiate between people with different lung capabilities. Moreover, we could also determine different ranges for a healthy lung. However, it would take a lot of time as well as study to be able to determine such a scale, but is done so, it would be very easier to use this kind of a spirometer. Then, there can also be a slight possibility of using this spirometer on a professional level.

8. CONCLUSIONS

With the manufactured spirometer we were able to determine an indirect measure of the lung capacity as the speed of rotations (RPM). Also, the project provided us with a wholesome hands-on experience of manufacturing a productive device from scratch.

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- Deciding the dimensions of the components
- Full system assembly
- Coding and setting up the NodeMCU
- Final video presentation and demonstration

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- CAD Modelling the components
- Preparing the file formats for 3d-printing/Laser cutting
- Final Report Writing & Compilation