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SPIROMETER

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ABSTRACT

The COVID-19 pandemic hit globally in December 2019 when a virus strain from Wuhan, China started proliferating throughout the world. This disease is so contagious, such that cluster outbreaks occur very frequently. The exposed patients make uninfected people susceptible to the virus. If the patients with symptoms quickly undergo testing and contact tracing, these outbreaks can be contained.

Studies show that COVID-19 patients have symptoms very similar to respiratory diseases such as Influenza, SARS and MERS. In that case, a doctor may suggest a spirometry test to see how well the medications are working and whether the breathing problems are under control.

In this vulnerable period, one must keep a spirometer at home to periodically check their oxygen levels. Spirometry is a safe test that requires the patient to breathe into a tube attached to the spirometer machine. During a spirometry test, the patient has to take a deep breath and breathe out as hard as they can for several seconds into the tube. The entire process takes a few minutes and the highest value in the reading indicates their Forced vital capacity (FVC). A FVC reading lower than normal suggests that breathing is restricted.

Keywords: COVID-19, respiratory diseases, spirometry test, oxygen levels, spirometer, Forced vital capacity (FVC), check restricted breathing.

NOMENCLATURE

rpm : Rotations per minute
N : Number of holes in slotted disk
CNC : Computer Numerical Control
MCU : Microcontroller Unit

1. INTRODUCTION

The spirometer is a device which is used to measure the extent of functioning of lungs. It is crucial in detecting early signs of COVID-19 infection in people and is also used in diagnosing asthma and other pulmonary diseases.
It consists of an impeller in a housing. A blow tube is attached to the housing in such a way that when the patient breathes out through the blow tube, the impeller starts rotating. This in turn rotates the shaft and consequently, the slotted disk. The LM 393 speed measuring sensor is placed in front of the slotted disk. There is a light device placed behind the slotted disk.

When the hole of the slotted disk coincides with the beam of light from the light emitting device, it is detected by the LM 393 sensor which gives an output as 1. the rest of the time, the output is 0. This output is then sent to the node MCU which then converts it to frequency which gives an idea of the lung capacity of the patient.

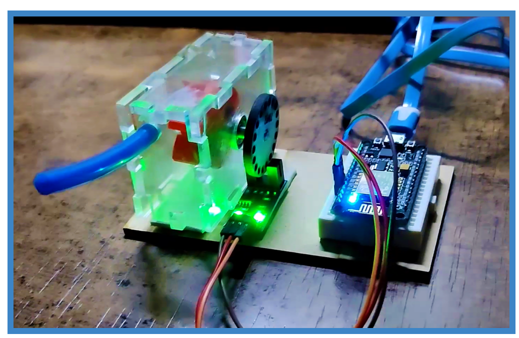


FIGURE 1: SPIROMETER

2. DESIGN

The dimensions of the base plate were given to be 120mm x 65 mm. Also, the thickness of the acrylic sheets provided was mentioned to be 5mm. The dimensions of all the parts have been decided based on this information.

2.1 Housing/Casing

The base of the housing is 65mm x 30mm. Since, the maximum height of the model was 50 mm and the base plate itself would be of 5mm thickness, the height of the housing is taken to be 45mm. Also, the length of the shaft was given to be 24 mm and around 10 mm of it would be inside the casing. That would have an impeller of 15 mm thickness attached on front of it in the casing. So 10+15 would make it a horizontal length of 25 mm. So, the breadth of the casing is taken to be 30 mm to be on the safe side.

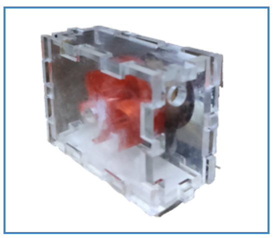


FIGURE 2: HOUSING/CASING

2.2 Shaft & Ball Bearing

The shaft is circular with a diameter of 5 mm. Both the ends of the shaft have a cut 1 mm thick measured from the diameter towards the centre. The length of this cut along the length of the shaft on both ends is 5mm. Such a shape ensures that the slotted disk and the impeller get attached firmly onto the shaft. The diameter of the bearing is 13mm and it has a thickness of 4mm. There is a hole present at the centre of the bearing having the same shape as that of the front portion of the shaft.

2.3 Impeller

The diameter of the base of the impeller is 30m so as to fit in the casing of length 65 mm. The impeller has a hole through its centre of the same dimensions as the ends of the shaft.

The blades are curved with a radius of 11mm and thickness 5mm. They protrude out from the base of the impeller for a distance of 10mm and they are placed around a circle of radius 15mm concentric to the shaft hole. After a number of trials, the optimum radius of the blades was selected to be 11 mm as this ensures that they are not too curved as they would fail to provide the necessary obstruction to the flow of air and they are not too straight as well because it would be too difficult to rotate them in such cases.

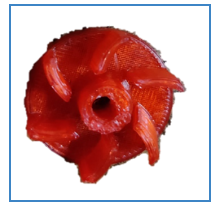


FIGURE 3: IMPELLER

2.4 Slotted Disk

The diameter of the slotted disk is 30 mm. It has a hole in its centre of the same dimensions as the ends of the shaft for the shaft to pass through.

The smaller holes used for measuring the rotational speed of the impeller are of diameter 3mm and their centres lie at a distance of 12.5 mm from the centre of the disk. This height of 12.5 mm was taken after considering the approximate height at which the speed measuring sensors are placed. There are eighteen holes placed at equal angles around the disk.

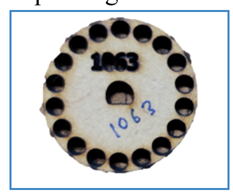


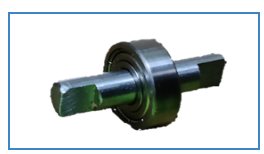
FIGURE 4: SLOTTED DISK

3. MATERIALS AND METHODS

3.1 Shaft & Bearing Assembly

Most of the ball bearings are made from chrome steel to provide excellent machinability and uniformity properties. Chrome steel has anti-corrosive properties that maximises the performance which is critical to support systems appications.

Ball bearing's individual parts - inner and outer rings and the bearing balls are manufactured using a multi step process. Automatic machines like lathes are used to get the basic shape of a ring, leaving extra materials for machining. The ball bearing starts out as a wire and undergoes a cold heading process to form a near net spherical shape.



.**FIGURE 5:** SHAFT AND BEARING ASSEMBLY

3.2 Slotted Disk

The slotted disk is also made from acrylic sheets in the same manner as the making of casing.

3.3 Housing/Casing

The casing is made up of acrylic sheets. Acrylic sheets are a kind of transparent plastic (this helps in observing the working of the impeller inside the casing)and is tougher than glass. The acrylic sheets are further cut using laser cutting. In it, a focused laser beam is used to melt some parts of the sheet so as to form the desired shapes which are controlled by a CNC machine. Instead of acrylic sheets, medium density fibreboard (MDF) sheets too can be used.

3.4 Base Plate

The base plate is made up of medium density fibreboard (MDF) sheets. MDFs are a mixture of wood fibres and resins which are compressed under high pressures and temperatures to create plate-like structures.

3.5 Impeller

The 3D printing details to determine shape, texture and strength of the product were rendered in a standard triangle language(STL). SLA technology is exercised to produce prototypes in a layer by layer fashion. Photochemical processes use light to melt and form cross links between PLA.

One of the most eco-friendly types of plastic is Polylactic acid(PLA). They are firm, smooth ,flexible and economical. A red colored plastic filament was deployed to 3D print a matte finished impeller.

3.6 Blow Tube

A pre-existing polyurethane pipe of appropriate dimensions is put in service. They are thin & flexible and hence can be used to direct a jet of air onto the impeller.

FIGURE 6: BLOW TUBE

3.7 Speed Measuring Sensor (LM393)

LM 393 is a widely available dual voltage comparator. It includes a rotary encoder that uses an optical coupling sensor to measure speed.

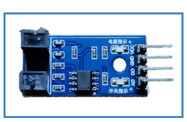


FIGURE 7: SPEED MEASURING SENSOR

3.8 Node MCU (ESP 8266)

Node MCU is a microcontroller that will be used for reading the output of LM 393 and displaying it on a computer. Further, conversion of data into physical signal and all other computation will be programmed on this Arduino-compatible component.

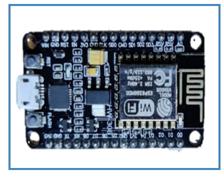


FIGURE 8: NODE MCU (ESP 8266)

3.9 Breadboard

A standard breadboard will be provided for ease of electrical connections and debugging.

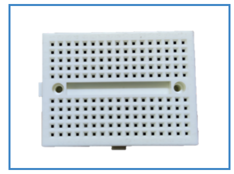


FIGURE 9: BREADBOARD

3.10 Jumper Wires

Jumper wires are widely accessible electrical wires that are connected with components in the breadboard. They have connectors or pins at each end that make it easy to connect without soldering.

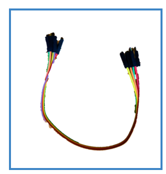


FIGURE 10: JUMPER WIRES

4. ALGORITHMS

The basic principle behind the working of a spirometer is that the speed of rotation of the slotted disk is a specification of the breathing capacity of the blower.

The speed of the slotted disk is marked by the number of rotations undertaken per minute(rpm). The following algorithm is implemented to evaluate rpm-

1. A while loop will run till count time = 1second.
2. If the light sensor is not blocked, it detects a hole and increases hole count by +1.
3. While the sensor remains unblocked, it is in the same hole, and therefore hole count should not change. A while loop is exploited to keep the program flow control within the if statement.
4. As soon as the hole passes, the if statement ends. The program flow returns back to the while loop.
5. Once count time >1, the while loop terminates.

5. RESULTS AND DISCUSSION

A spirometer measures how much oxygen is in someone's blood. People who have breathing difficulty may use a spirometer at home to check their oxygen levels. Low levels of oxygen can be an early warning sign of immediate medical care. A normal level of oxygen is usually 150 or a higher rpm.

The rpm is calculated at the using a simple formula -

$$\text{rpm} = \text{hole count} \times (60 / N) \quad (1)$$

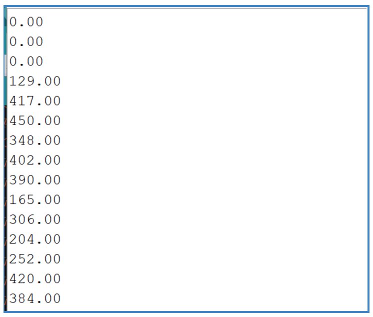


FIGURE 11: SPIROMETER READING OF A HEALTHY PATIENT

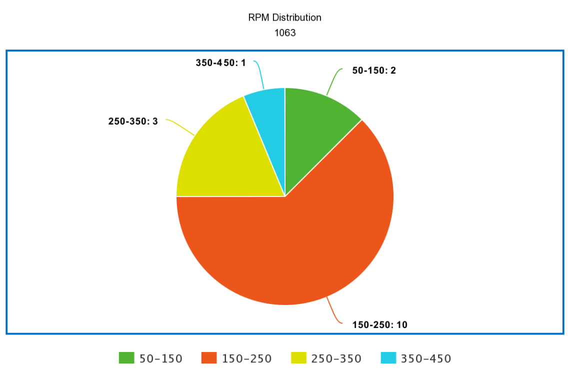


FIGURE 12: RPM LEVELS SPIROMETER CHART

6. CHALLENGES AND FAILURES

1. Appropriate geometric dimensioning requires a lot of interpretation and is a vital part of good designing.
2. A clearance of 0.2 mm was missed in the impeller & slotted disk which made the shaft assembly strenuous.
3. Blackballing tolerances lead to gruesome results. Few chiseling to snap fit and use of adhesives were needed to assemble the housing.
4. It was challenging to make out the team name on the impeller due to the inadequate embossing depth.

7. RECOMMENDATIONS AND IMPROVEMENTS

1. A larger extrusion in the back side of the housing can reduce the obstruction on the air flow and increase the rpm of the impeller.
2. Reduced breath of the housing will keep the blow pipe and impeller in proximity and increase the rpm.
3. Adhesives must be carefully applied while assembling ball bearing, since it may hinder its motion.

8. CONCLUSIONS

Spirometer is a simple machinery of medical importance that can be manufactured using the current trend of automation such as advanced robotics, additive manufacturing and principles of interoperability.

ACKNOWLEDGEMENTS

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We would also like to express deep appreciation and indebtedness to Prof. Madhu Vadali for his endless support, kind and understanding spirit during the entire project.

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CONTRIBUTION

For Task 1, Ksheer Agrawal calculated the dimensions of all the parts, made the 3D model of the impeller, wrote the code for the working of the node MCU and made the full assembly in Autodesk. Task 2 (actual assembly + video of the assembly process, the final product, and the working of the final product) was done by Ksheer Agrawal. In task 3, the Abstract, Algorithms, Recommendations and improvements Results and discussion, conclusions, acknowledgements and parts of nomenclature, design and materials and attached images were written by Ksheer Agrawal.

For Task 1, Ishani Chogle calculated the dimensions of the housing/casing and made the 3 D models for housing/casing and slotted disk. For Task 3, the introduction, contribution and parts of nomenclature, design and materials was written by Ishani Chogle.