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Concept design of the physical structure for ICU ventilators for COVID-19 pandemic



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ABSTRACT

A new disease known as COVID-19 caused by the SARS CoV2 virus has engulfed the entire world and led to a global pandemic situation. Till December 9, 2020, the disease has infected 68 million people worldwide and more than 1.56 million people have been killed. The origin of the COVID-19 disease has been traced back to the bats, but the intermediary contact is unknown. The disease spreads by respiratory droplets and contaminated surfaces. In most cases, the virus shows mild symptoms such as fever, fatigue, dyspnea, cough, etc. which may become severe if appropriate precautions are not adhered to. For people with comorbidities (usually elderly) the disease may turn deadly and cause pneumonia, Acute Respiratory Distress Syndrome (ARDS), and multi-organ failure, thereby affecting a person's ability to perform normal breathing which may put them on ventilator support. The virus causes Acute Respiratory Distress Syndrome (ARDS) that can lead to multi-organ failure in the most severe form. A patient suffering from ARDS must be put on a mechanical ventilator. These assistive devices help patients with respiratory disorders perform normal breathing. Presently nearly sixty thousand COVID-19 patients are in critical condition worldwide, fighting for survival requiring ventilator support. In India, the number stands close to eight thousand such individuals especially when the second wave of COVID-19 is expected to spread globally with initial signs arising from European and Middle East countries. With a large number of patients requiring ventilators, it puts a huge strain on the already weak health infrastructure of the developing countries. This is where some manufacturing and automobile companies have stepped in to help hospitals by developing ventilators at a faster rate and lower costs without compromising on the quality with the support of different government initiatives. This paper aims to study the basic requirements to be considered while designing the physical structure of an elementary level ICU ventilator for the hospital environment. The challenges related to research in electronic wiring of a mechanical ventilator, the overall structural design, and surrounding base could be appropriately done for different loads by simulating the conditions on tools like ANSYS software with accurate dimensions which could improve their future designs.

1. Introduction

A recent study on COVID-19 explains the nature of the disease and how to control the spread of the virus [1]. SARS CoV 2 is a respiratory pathogen; the virus binds onto ACE2 receptors which are mainly found in our epithelial layer of alveolar cell-associated the respiratory tract [2].

Due to the attack of these viruses as an immune response patient's body starts to produce cytokines heavily which leads to inflammation in the lungs [4]. This inflammation affects the performance of lung alveoli which causes trouble in carrying out the respiration process [5]. Due to this, the patient's body starts to lose energy due to lack of oxygen available in the cells which affects the body's homeostasis condition.

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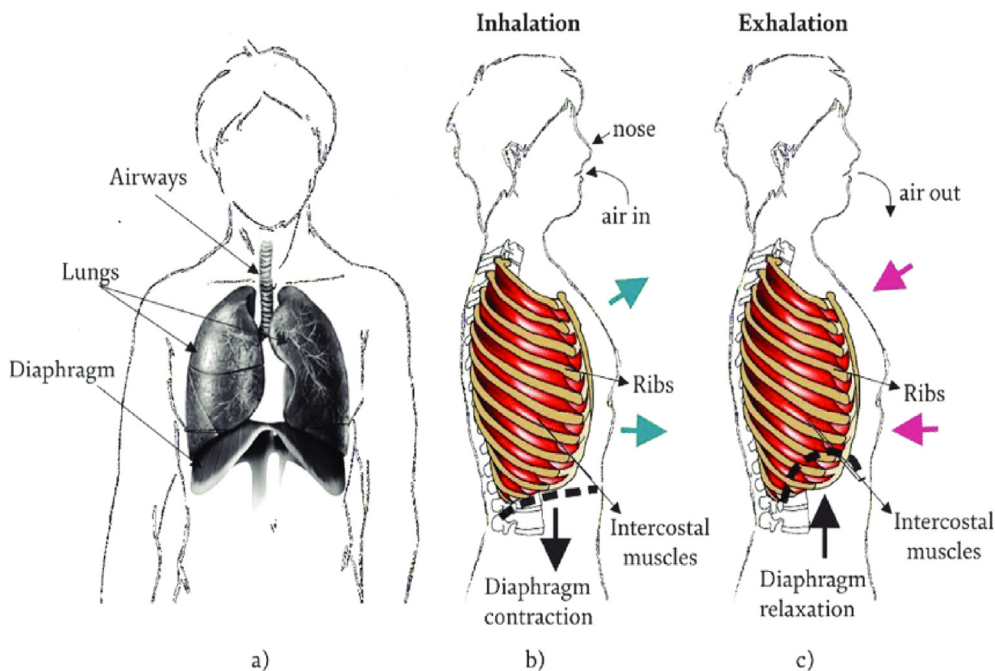


Fig. 1. Breathing process in Humans illustrated. Source: Breathing Monitoring and Pattern Recognition with Wearable Sensors - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Breathing-process-a-structures-involved-in-the-breathing-process-b-inhalation_Fig_1_333694274 [accessed 11 Jul 2020].

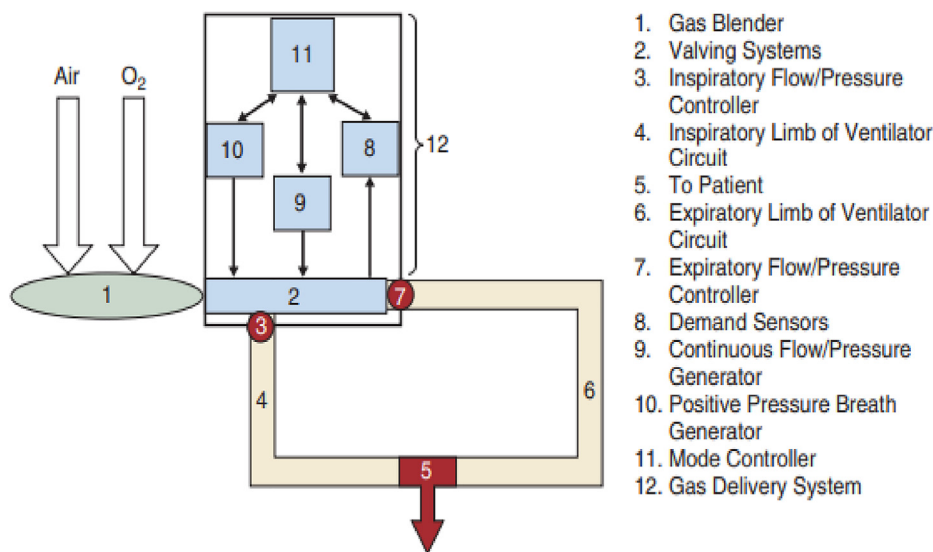


Fig. 2. A flow chart of ventilator parts and processes [11].

Sustainable breathing solely by the patient's muscles becomes difficult to continue and the need arises for external support i.e. a mechanical ventilator is to aid in the breathing process and overcome respiratory distress [6]. SARS-CoV 2 has made a significant impact on the health infrastructure this impact can be seen easily witnessed at the time of writing this paper, the disease has infected 68 million people worldwide and more than 1.56 million people have been killed [7], and presently more than sixty thousand COVID-19 patients are in critical condition worldwide, fighting for survival and requiring ventilator support. In India, the number stands close to eight thousand such individuals [8].

The need for mechanical ventilation arises when a patient's body

becomes fatigued to continue the natural breathing process i.e. inhalation and exhalation of air. This happens mainly during a critical illness such as COVID-19 or surgery. A mechanical ventilator, therefore, does the work of muscles involved in breathing by a continuous supply of O₂ to the patient during inhalation and removing carbon dioxide (CO₂) during exhalation. A ventilator does not help in healing the patient rather it stabilizes the body while medications or surgery cure the patient [1].

According to Chatburn "A mechanical ventilator is a device that converts energy using its driving mechanism in a preordained manner with help of control circuit to aid or replace a patient breathing mechanism" [9]. According to this definition, even a handheld self-inflating

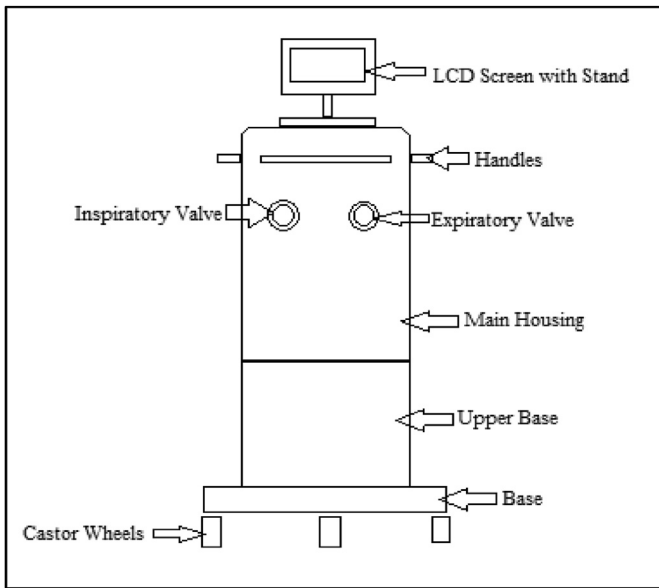


Fig. 3. A rough sketch defining how the ventilator might look.

bag-valve resuscitator is a ventilator, however, a mechanical ventilator should be fully automatic, such that a person could set it up and move away from it without any difficulties. An ICU ventilator is one of the most sophisticated types of mechanical ventilators. It is developed with maximum safety features for the patients who are admitted to ICU and require critical care. Ventilators are generally prescribed for a short time duration as several hazards exist with their long-term usage such as barotrauma [4]]. This manuscript aims to study the design and operational mechanics of invasive mechanical ventilators that can be employed in the hospital intensive care units (ICUs) designed with software future prototype that could probably serve as a low cost, easy to manufacture, and assembled as an alternative to more sophisticated and automated ventilators that are currently present in the market.

2. Working concept

The mechanical ventilator is used to replace a patient's natural breathing process, it is important to know how breathing occurs in the human body to understand the ventilator's working concept. As shown in Fig. 1, two muscle groups typically act to control breathing, the diaphragm-a large muscle separating the abdomen and the chest and the intercostal muscles-muscles present between rib cages. During inhalation, the diaphragm contracts, causing it to move towards the abdominal cavity while the intercostal muscles also contract, lifting the rib cage outwards [10]. This muscle movement causes an increase in the volume of the thoracic cavity leading to a decrease in pressure which allows

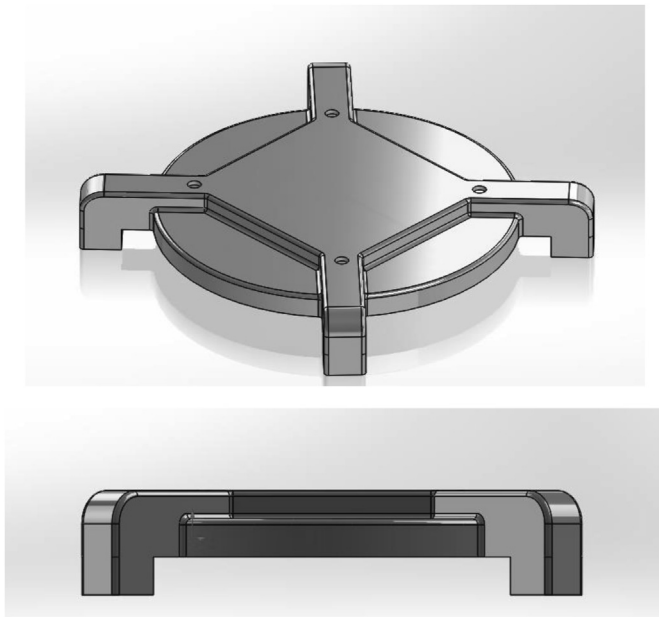


Fig. 4. Different views of the Base.

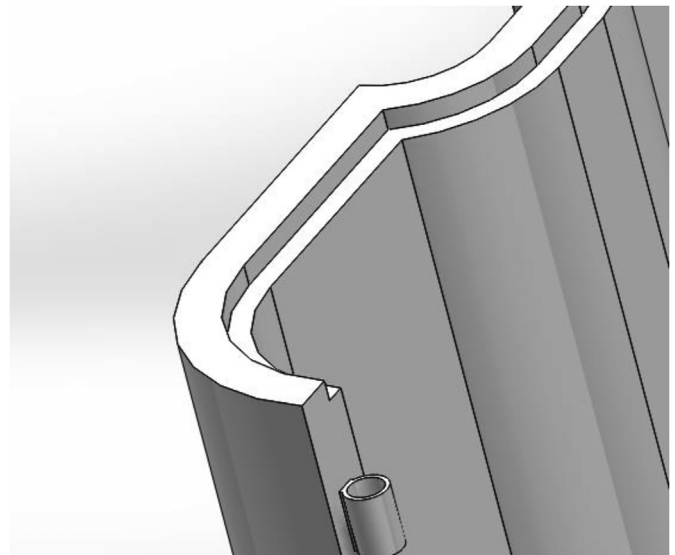


Fig. 6. Groove provided for the main housing to mate into.

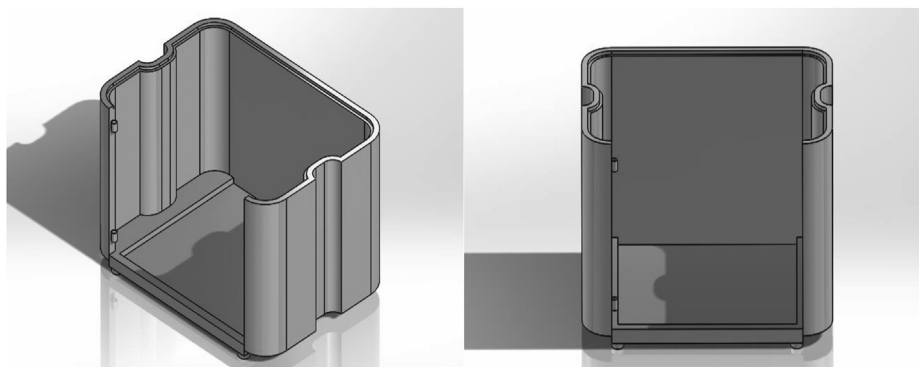


Fig. 5. Various views of the design.

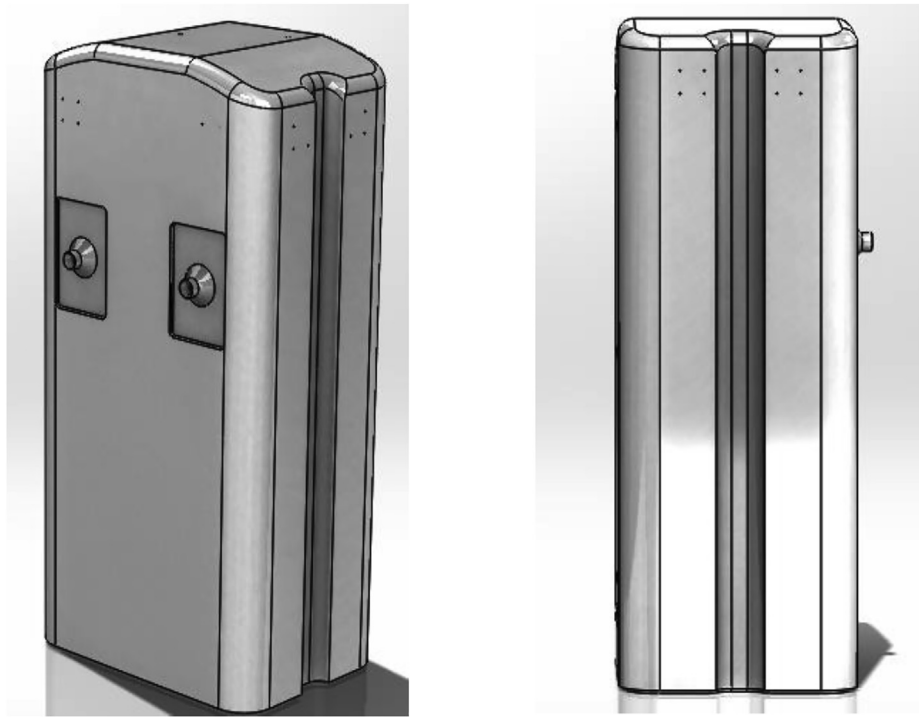


Fig. 7. Front View showing two holes meant for inspiratory and expiratory valves and a side view showing holes to mount Handles.

outside air at atmospheric pressure to fill up the lungs and equalize the pressure. The important thing to note here is that Negative Pressure drives inhalation. The same process is reversed to drive exhalation with a small spike above atmospheric pressure to push air out of the lungs.

On the other hand, Mechanical Ventilators cannot function like natural lungs, they induce and supply air into the lungs using Positive pressure i.e. raising pressure inside the circuit above atmospheric pressure to drive inhalation, essentially like a process of filling up a balloon [11]. This can have severe effects on the lungs if the process is not closely monitored and controlled [12], therefore, ICU ventilators tend to be quite sophisticated. Hence, a mechanical ventilator must induce pressure to initiate flow through the circuit through tubing connecting the patient to the ventilator and accordingly increase the lung volume as required.

3. Breathing model and its equation of motion

From the above explanation of the breathing process, it becomes clear that pressure, volume, and flow are the driving variables in the ventilation process. To get an idea of the pressure, volume, and flow involved in breathing we simplify the biological process [2], the physical model of breathing mechanics is assumed to be a series of rigid pipes connected to an elastic bag. We get an equation [11].

$$[\text{muscle pressure} + \text{ventilator pressure} = (\text{elastance} \times \text{volume}) + (\text{resistance} \times \text{flow})] \quad (1)$$

or

$$[\text{muscle pressure} + \text{ventilator pressure} = (\text{volume} / \text{compliance}) + (\text{resistance} \times \text{flow})] \quad (2)$$

Equation(s) 1 and 2 defines the relationship between volume, pressure, and flow during the ventilation process and is acknowledged as the equation of motion of the respiratory system.

Some key terms in the above equation and their definitions are (Chatburn R. L., 2003).

- Muscle Pressure: It is an imaginary respiratory pressure (immeasurable) applied by muscles to expand the thoracic cavity and lungs.
- Ventilator Pressure: Respiratory pressure generated by the ventilator to induce ventilation to the lungs
- Elastance: It is the ratio of change in pressure to change in volume
- Resistance: It is the ratio of change in pressure to change in flow

It is to be noted that both Elastance and Resistance together form the load against which the muscles and ventilators do the work.

From the equations, we infer that:

- If the ventilator pressure equals zero, muscles do all the work to carry out breathing. This is unassisted and normal breathing
- On the other hand, if both ventilator and muscle pressure are non-zero values, the patient performs work and the ventilator provides support to carry out breathing, this is known as partial ventilatory support.
- If the muscle pressure is zero, the patient depends on the ventilator to provide work to carry out breathing this is known as total ventilatory support [11].

4. Components of a mechanical ventilator

To make a good physical structure design for an ICU ventilator, we need to know what parts are going to reside inside the structure.

A mechanical ventilator consists of three main categories with safety features as listed below:

1. Power Sources
 - a. Gas supply
 - b. Power supply
2. Control of Gas Delivery
 - a. Gas Blender
 - b. Inspiratory Flow Regulator
 - c. Humidification Equipment



Fig. 8. Rearview which shows gate for ease of access and at the bottom, holes for attaching medical air hoses.

- d. Patient Circuit
- e. Expiratory Pressure Regulator (PEEP valve)
- 3. Monitoring
 - a. Sensors
 - i. Gas Concentration
 - ii. Flow
 - iii. Pressure

Safety Features.

1. Gas intake particle filter
2. Pre-circuit bacteria filter
3. Moisture traps & Heat/moisture exchange systems
4. Expired gas Filter

To see the involvement of these parts in the process of ventilation is represented in Fig. 2.

5. Detailed analysis of each component and assumptions

5.1. Power source

A positive pressure ventilator typically utilizes compressed gas or electric supply as its power source. Electric ventilators use electricity to drive compressors which supply compressed air to ventilate the patient.

Compressed gas ventilators directly utilize compressed air and oxygen supplied by wall gas connections or cylinders in a hospital to ventilate patients, generally, ICU ventilators use compressed gas to drive inspiratory flow however electricity is utilized to power valves and switches. Compressed gas-powered ventilators tend to be highly energy-efficient as they utilize electricity only to power their valves and control system [11].

5.2. Assumptions made in ventilator designing

Considering our ventilator to be used in intensive care units or ICU we assume that the gas supply would be provided by either piped wall O_2 and air present in most hospital ICUs or compressed O_2 and air supplied using cylinders. Considering the ventilator to be non-invasive as it is suggested by research to be more effective and less harmful to the patient being ventilated [3,14], it also reduces the chance of transmission of the virus such as COVID-19 through the endotracheal tubing [15]. Although, non-invasive ventilation can also aerosolize the virus which poses a risk to healthcare workers operating in the ICU therefore proper precautions are required while ventilating patients. A positive pressure ventilator requires the supply flow rate achievable by the gas supply to be 240 L/min to account for gas leakage around the mask on patients' faces. This flow rate is achievable only through the gas from the wall or cylinder [17]. Based on our assumptions that the inspiratory flow would be completely generated by the gas supply, electricity supply would hence be used only to power the ventilator display, inspiratory, and PEEP solenoid valves which are electrically activated. The ventilator also includes an inbuilt battery backup to ensure continuous ventilator operation even in the case of hospital power failure.

5.3. Control of gas delivery

A control system is embedded into an ICU ventilator to ensure that the breathing pattern produced is exactly as determined by the caregiver. A control system enables the caregiver to alter settings of air delivery such as the size and frequency of breath, the effort needed by the patient to instigate inspiratory and expiratory breath [9,17]. The different components required are:

1. **Gas Blender:** It controls the mixture of air, O_2 , and anesthetic gas to be delivered to the patient. In our ventilator, it is required to blend O_2 and Air mixture only. This is not required in a ventilator if it needs to be stripped-down to domiciliary version [17] which runs on room air alone, but since we are designing an ICU ventilator it is an important component that needs to be considered.
2. **Inspiratory Flow Regulator:** It ensures variation of gas flow according to the patient's needs; it is essentially just a solenoid valve that directly attaches to the ventilator. Given that the wall gas in ICU piping outlets is supplied at a typical pressure of 400 kPa (approximately 4 atmospheres), it is a vital component.
3. **Humidification Equipment:** It is a major requirement in most settings. This can take the form of an active humidifier such as a tool that heats and evaporates water into the supplied gas mixture) or a passive humidifier such as a heat/moisture exchanger. Since we are considering our ventilator to be non-invasive, we can do away with a humidifier, but it is generally recommended to have one in the system to reduce the symptoms of chest congestion and dryness thereby improving patient comfort and compliance.
4. **Breathing Circuit:** It is the tubing and piping which delivers the gas from the ventilator to the patient, its key design features are:
 - a. Simple Design
 - b. Lightweight
 - c. Biologically inert
 - d. Single-use, Disposable
 - e. Gas impermeable
 - f. Low resistance to flow and low compliance.

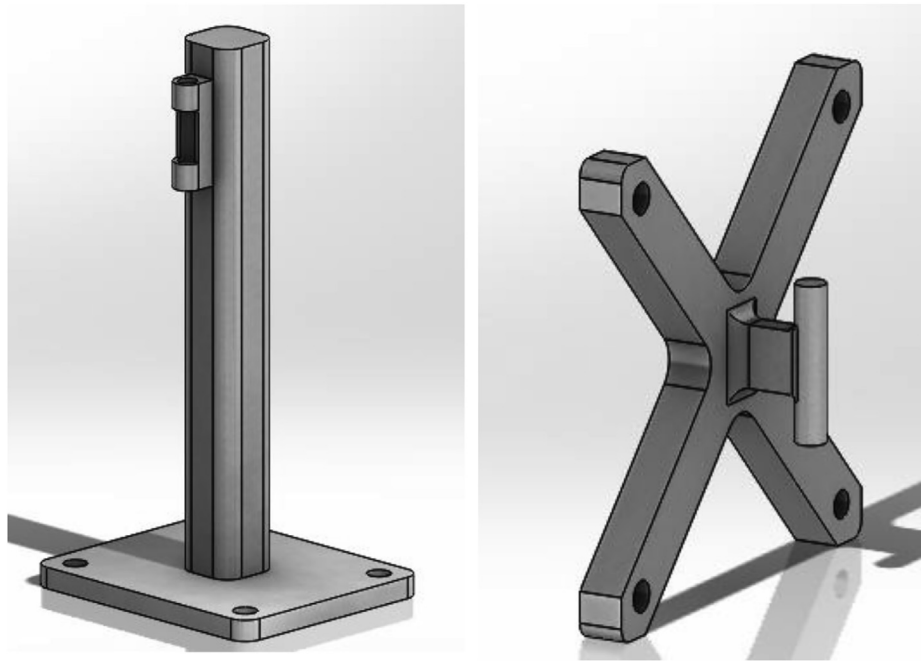


Fig. 9. The stand which is mounted on the ventilator and the extension of the stand which will attach to the Monitor.

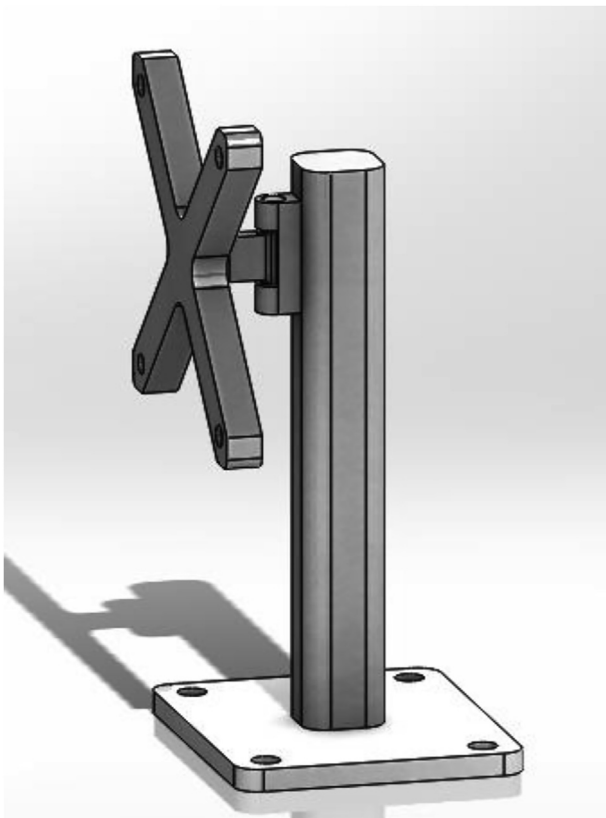


Fig. 10. The complete assembly view.

5. **Expiratory Pressure Regulator (PEEP valve):** It is known as a solenoid valve that controls the expiration of air from the ventilator to maintain a minimum positive pressure or Positive End Expiratory Pressure (PEEP) inside the lungs so that alveoli don't collapse or get shut out during the ventilation process [11].

5.4. Monitoring systems

Many positive pressure ventilators incorporate sophisticated sensors such as pressure, gas concentration, volume sensors to monitor and control the ventilator's input and output to display vital patient information onto the inbuilt display of the ventilator [9,17]. A list of such sensors crucial in an ICU ventilator unit is listed below.

1. **Gas Concentration Sensors:** There are three types of sensors
 - a. **Paramagnetic Sensors:** The sensor takes advantage of the paramagnetic characteristics of oxygen. When a stream of oxygen coming from a sampling line is disturbed (deflected away or towards the sensor) by the magnetic field produced. This causes a change in the sampling line gas pressure resulting in a switching change that can be used to detect changes in oxygen concentration. The disadvantage of paramagnetic sensors is required to direct the stream to a parallel "sampling" line which causes a delay in the results and the delay is proportional to the rate of flow in the sampling line [17,18].
 - b. **Galvanic Sensor:** These sensors are "oxygen cells" in which oxygen causes a chemical reaction across a membrane and this reaction produces a voltage in the accompanying electrical circuit. The voltage directly corresponds to the concentration of oxygen in the flow. A disadvantage of these types of sensors is that they run out of fuel that causes a chemical reaction in 1–3 years and need to be replaced [19]. However, this type of sensor is widely used in several ventilators and is readily available [17]. Therefore, we will be utilizing this sensor in our ventilator design.
2. **Flow Sensor**
 - a. **Ultrasonic flowmeters:** They are commonly used as flow sensors. In these type of sensors, typically two transducers which function as both emitter and receivers emit ultrasonic waves which reflect from the intervening medium (such as air or Oxygen supply). The delay in transmission and reflection of the waves corresponds to the flow in the pipe [17,20].
 - b. **Hotwire (or hot film) anemometry:** In this, a platinum wire is heated to a certain temperature and its resistivity is constantly measured. As the air flows over the wire it cools down the wire,

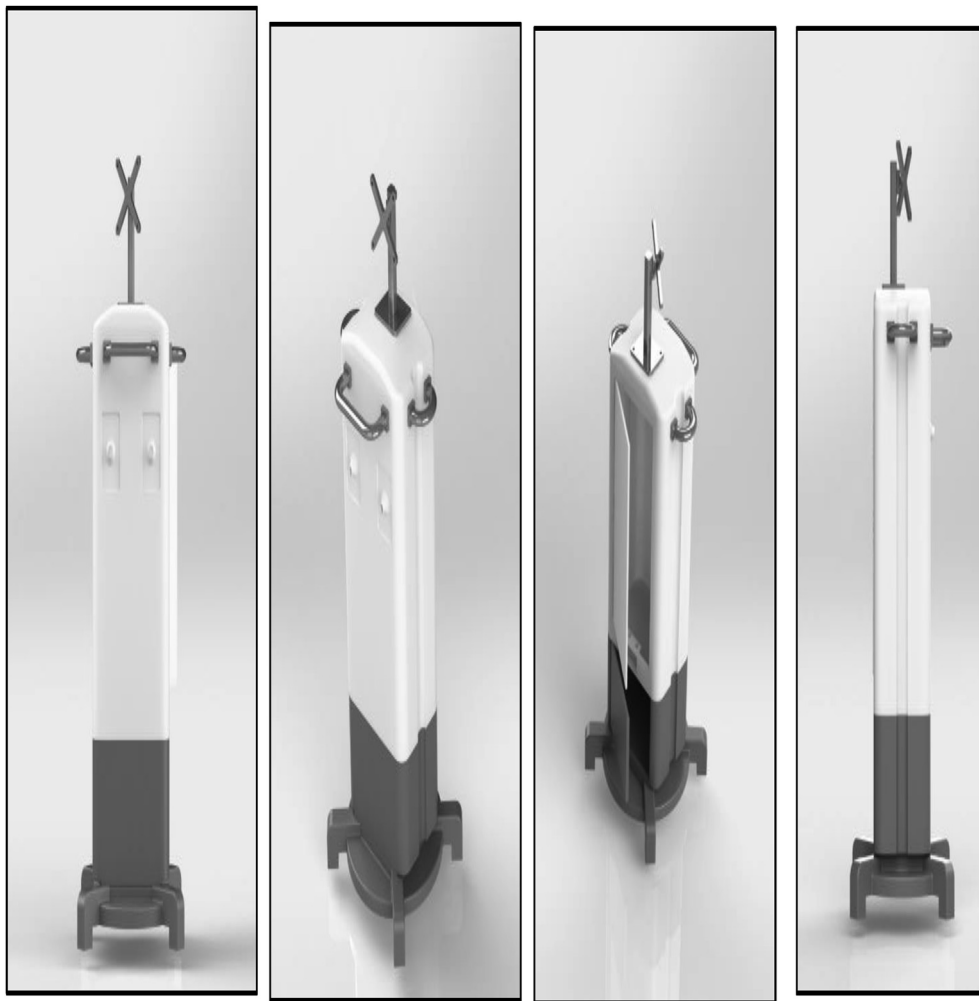


Fig. 11. Final rendered images.

Table 1
Mechanical properties of sustarin C, source [24].

Mechanical Properties	Guideline Value	Unit
1. Yield Stress	67	Ma
2. Elongation at Break	30	%
3. Modulus of Elasticity	2800	MPa
4. Impact Strength	6	KJ/m ²

Table 2
Thermal properties of sustain C, source: (Technical datasheet sustarin C).

Thermal Properties	Guideline Value	Unit
1. Melting Temperature	165	Celsius
2. Thermal Conductivity	0.31	W/(m*K)
3. Coefficient of Linear Thermal Expansion	110	10 ⁻⁶ /K
4. Thermal Capacity	1.50	KJ/(Kg*K)
5. Service Temperature Long term	-50 to 100	Celsius
6. Service Temperature Short term	140	Celsius

hence bringing down its resistivity. The cooling of wire is a predictable phenomenon and the faster it cools down could lead to the calculation of airflow in the tube. We will be using these sensors to measure the flow of gases at three locations, near the inspiratory valve, near the expiratory valve, and the patient's mouth [17,21].

3. **Pressure Sensor:** Using Strain gauge transducers to measure the resistance change in some components of the diaphragm, which

Table 3
Mechanical properties of [29]; source (technical datasheet [30]).

Mechanical Properties	Guideline Value	UNIT
1. Hardness	85	Shore D
2. Tensile Strength	16000	Psi
3. Tensile Modulus	500000	Psi
4. Elongation at Break	20	%
5. Compressive Strength	18000	psi
6. Rockwell Hardness	126	R
7. IZOD Impact Notched	1.2	Ft-lb/in
8. Shear Strength	7700	psi
9. Coefficient of Friction	0.4	

Table 4
Thermal properties of SustaPEEK, source [23].

Thermal Properties	Guideline	Unit
1. Thermal Conductivity	1.73	in/hr./ft ² /F
2. Melting Point	630	Fahrenheit
3. Continuous Service Temperature, Air	480	Fahrenheit
4. Coefficient of Linear Thermal Expansion	2.6	in/in/F*10 ⁻⁵
5. Deflection Temperature at 1.8 MPa (264 psi)	320	Fahrenheit
6. Deflection Temperature at 1.8 MPa (66 psi)	360	Fahrenheit
8. Flammability	1/8 inch	V-0

changes the current through the circuit such as employing Wheatstone bridge transducers are an example of the pressure sensor. This

change in current is used to calculate the corresponding pressure of air or oxygen in the ventilator [17,22].

5.5. Safety features

Filters within the mechanical ventilator perform a crucial function. They protect the patient from airborne filth which could be blowing around within the gas supply systems or in the air present in the room. The filters also protect the fragile parts inside the ventilator from the corrosive swamp gas that is exhaled by the patient. Lastly, the crucial function, the filters protect the caregiver and their co-workers from exhaled pathogens particularly in the case of diseases like COVID-19 [13].

Filters are mainly placed at three key positions in a respiratory circuit connected to the mechanical ventilator: at the gas intake, near the patients' mouth, and in the expiratory circuit [17].

1. Gas intake particle filter: Used right after intake of gas into the ventilator from the wall source, these filters get rid of any dust or other particles that might sweep in with the gas intake.
2. Pre-circuit bacteria filter: Placed at the joint connecting the breathing circuit to the ventilator it clears any presence of bacteria in the gas before it enters the patient's lungs.
3. Moisture traps and Heat/moisture exchange systems: As the name suggests they trap moisture that gets accumulated inside the breathing circuit to ensure no bacteria grows in the breathing circuit.
4. Expired gas Filter: It protects the people present in the ICU ward from contracting diseases that the ventilated patient may expire through his lungs into the air.

6. The design

For the ventilator design, we decided to take an estimated set of dimensions regarding the ventilator's height, breadth, and width. This estimation is made by analyzing the typical dimensions of various commercial ventilators available in the market.

The dimensions selected are as follows:-

Height: Min 145 cm and Max 160 cm.

Breadth: Min 30 cm and Max 40 cm.

Width: Min 32 cm and Max 45 cm.

Based on these dimensions, we prepared a rough sketch of how the ventilator might look as per the sketch shown in Fig. 3.

The ventilator design is broken down into the following parts which were designed in the SOLIDWORKS software part modeling and later on combined into SOLIDWORKS assembly. The parts are:

1. Base: Used for moving the ventilator around, incorporates castor wheels for ease of movement.
2. Upper Base: Used to store battery packs and various other parts of a ventilator, it would have a gate for ease of access.
3. Main Housing: This part will incorporate all major ventilator parts such as inspiratory valves, electric circuits, gas circuits, etc.
4. LCD screen with Stand: A basic view of how the ventilator would function with a fixed stand and moveable screen for easy viewing angles.

6.1. Base

The base with its dimensions is shown in Fig. 4. The base is designed such that its legs we can attach to the castor wheels. The top part of the base has four holes that can mate with a male counterpart designed at the base of the next part which lies on top of the base which helps in ease of

assembly.

6.2. Upper base

The upper base design specifications have various fillets and grooves to make the design look aesthetically good as shown in Figs. 5 and 6. At the rear, there is a gating mechanism that provides for ease of access to the components kept inside. If one observes closely at the top portion of the design, we have provided a groove for the main housing to mate onto the top of the upper base.

6.3. Main housing

The main housing has been designed to house most of the major ventilator components, sensors, piping, etc. The ventilator is designed with slots for attaching inspiratory and expiratory valves at the front, holes to connect medical air and oxygen at the back, holes to screw handles, and a monitor stands as shown in Figs. 7 and 8.

6.4. Monitor stand

In an ICU ventilator, the most important aspect is its control and data which is shown using a screen that is usually the size of an average 15" Laptop screen. To hold this screen and tilt it in any direction possible, we designed a monitor stand on top of the ventilator. It has hinge-like support to move the ventilator screen 180° in the horizontal plane for easy viewing angles as shown in Figs. 9 and 10 (see Fig. 11).

7. Material for designing the physical structure of the ICU ventilator

Due to the rapid growth in the medical line, nowadays a lot of research is going in the area of biomaterials. The biomaterials include all the related materials which can be utilized in the area of medical sciences [24]. Designing and Manufacturing an ICU ventilator takes into consideration features such as functionality, reliability, and process stability. The material employed must be of the highest medical standards to treat the patient safely. Thermoplastics are a suitable material for the structural design of all modern ICU ventilators. The most common materials used to manufacture the outer structure of ICU ventilators are POM-C, PEEK, PEI, and PVDF [25,26].

These are the thermoplastics that are used as the basic proposition for the material employed in making the structure, but each manufacturer does not have the same set of requirements as far as specifications are concerned. The manufactured derivatives of PEEK, POM-C, and PEI have different names and vary with different manufacturing companies but the basic constituents in the material and their properties remain the same (see Table 1).

1. SUSTARIN C: This material has Poly-oxy-methylene (POM) as its basic constituent and it is an engineering thermoplastic used in precision parts that have the requirements of high stiffness, low friction, and perfect dimensional stability as shown in Tables 2 and 3 [23]. It goes by the other names such as Ultracon, Duracon, Ramtal, Kepital, and Celcon, etc. All these above-mentioned names have different chemical manufacturers and show slightly different formulas [28].

POM is generally supplied in its granulated manifestation, but it is possible to convert it into the desired shape by applying pressure and heat. The two most common methods which are generally used to manufacture this material are Injection Molding and Extrusion. POM is generally extruded as continuous lengths of either round or rectangular section, although these sections can be cut to length and sold as simply a

bar or sheet stock for machining [25].

An ICU Ventilator's physical structure is made up of material SUSTARIN-C that will have good chemical resistance, high dimensional stability, and low moisture absorption.

2. **SUSTAPEEK:** It is a colorless organic thermoplastic that has Polyether ether ketone (PEEK) as its basic constituents. This material is a semi-crystalline thermoplastic having excellent mechanical and chemical resistance properties, and these retainable even at high temperatures. The manufacturing process shows great effects on crystallinity and hence the mechanical properties [16,27]. PEEK is widely used to fabricate the items used in applications such as pumps, bearings, piston parts, and medical healthcare, etc. it is an advanced biomaterial and is also used in medical Implants as shown in Tables 3 and 4 [29].

We recommend using [30] for the physical structure provided by ROCHLING INDUSTRIES INDIA because of the following characteristics.

- a. Excellent Dimensional Stability
- b. Flame Retardant
- c. Self-Extinguishing
- d. Very Low Smoke Density
- e. Good Sliding Properties
- f. Hydrolysis Resistant, even against superheated steam
- g. Creep resistant
- h. Good Chemical Resistance [30].

7.1. Result

After following various considerations and assumptions listed above for the project "design of the physical structure of an ICU ventilator" we successfully designed the structure using SOLIDWORKS software. The following images are the final renders of our design with the material attributed to the parts.

7.2. Conclusion

A report from India Today dated 10th April 2020 stated that India had about 40,000 ventilators for a population of 1.3 billion and at least 10% of total COVID-19 cases required ventilator support. According to these numbers, hospitals require a buffer of 100,000 ventilators [31]. After nearly three months of this report the total cases in India stands at 850,000, India is now the 3rd in the list of worst-hit Countries due to COVID-19 after the USA and Brazil [7]. The requirement of these ventilators is now more crucial than ever before especially when the second wave of COVID-19 is expected to spread globally with initial signs arising from European and Middle East countries. With the growing number of critical patients requiring ventilator support, it has become essential to design and manufacture ICU ventilators at an extremely fast rate and with cost minimization in mind by using elementary features. The complete process of our research and development in this project took us just over a month. The primary objective of this project was to design an aesthetically smooth and robust structure that provides features such as ease of assembly, ease of servicing, and ease of manufacturing and ergonomic design to the industry and the end-user. However, due to limited information access and lockdown in various states a prototype could not be developed, our next step would have been to test the practicality of the design and optimize it according to various limitations encountered while developing and testing the prototype. Some areas for example where we believe the design falls short is, the dimensions and

characteristics of the wiring and electronics that need to be embedded inside the ventilator are not known therefore the design couldn't be optimized for them. It is not clear if the design could sustain the load when completely assembled, the walls and base of the ventilator could be altered to the appropriate loading conditions. The castor wheels could be designed completely in-house to save cost. We can overcome these challenges by some further research into electronics and the wiring of a mechanical ventilator, the walls and base could be appropriately designed for different loads by simulating the conditions on tools like ANSYS and correcting the dimensions appropriately.

Declaration of competing interest

The Authors report no conflict of interest for submitting paper titled "Design of Physical Structure of an ICU Ventilator for Novel Corona Virus Disease (COVID-19)" to the Sensors International Journal.

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