

Design and Development of Emergency Based Portable Ventilator


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Portable ventilators with integrated patient monitoring systems significantly advance respiratory care, offering essential support for individuals with breathing difficulties. These sophisticated, mobile medical devices deliver mechanical ventilation through various modes such as volume- controlled and pressure-controlled ventilation customized to the specific needs of each patient. The integration of comprehensive monitoring capabilities allows for the real-time tracking of vital signs including heart rate, oxygen saturation, and respiratory rate, ensuring continuous and accurate assessment of patient status. The portability of these ventilators enhances their utility across diverse environments, including emergencies, home care, and patient transport, where immediate and adaptable respiratory support is crucial. This paper explores the design, functionality, and clinical applications of portable ventilators with patient monitoring systems, highlighting their role in improving patient outcomes and expanding the scope of respiratory care.

Keywords: low-cost Portable Ventilator, covid-19, pandemic, mechanical with electrical and electronic combination, medical hardware, artificial respiration

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1. Introduction

Effective respiratory support is vital in emergency situations, yet traditional ventilators are often impractical in remote or resource-limited settings due to their size, cost, and power requirements. To address these challenges, we have developed a portable, battery-operated ventilator designed for rapid deployment in emergencies. This device offers reliable respiratory support with user-friendly features, ensuring ease of use and adaptability across various scenarios. Our goal is to enhance critical care accessibility and improve patient outcomes in diverse and challenging environments.

In emergency medicine, the ability to provide rapid and effective respiratory support can be the difference between life and death. Traditional mechanical ventilators, though indispensable in intensive care units, are often cumbersome, costly, and dependent on continuous power supply, limiting their utility in pre-hospital, remote, and resource-limited settings. Natural disasters, pandemics, and mass casualty incidents further exacerbate the need for portable and versatile respiratory support systems.

The COVID-19 pandemic underscored the global demand for scalable ventilator solutions capable of addressing sudden surges in patients requiring respiratory assistance. This highlighted the urgent necessity for a device that combines the efficacy of traditional ventilators with the portability and independence needed in diverse emergency scenarios.

In response to this critical need, we have developed an emergency-based portable ventilator designed to deliver immediate, reliable respiratory support across various settings. Our device is lightweight, battery-operated, and capable of providing both invasive and non-invasive ventilation. It incorporates advanced sensor technology to monitor and regulate airflow, pressure, and oxygen levels, ensuring precise and adaptable patient care.

Initial testing has demonstrated the ventilator's reliability, ease of use, and effectiveness under simulated emergency conditions. By offering a cost-effective and scalable solution, this portable ventilator aims to significantly enhance the capacity to deliver critical care in emergencies, thereby improving patient outcomes and healthcare resilience.

Advancements in medical technology have significantly transformed respiratory care, particularly through the development of portable ventilators with integrated patient monitoring systems. These devices have become indispensable in managing patients with acute or chronic respiratory conditions by providing essential mechanical ventilation and continuous real-time monitoring. Unlike traditional, stationary ventilators, portable units offer flexibility and mobility.

Portable ventilators are engineered to deliver mechanical ventilation in multiple modes, including volume-controlled and pressure-controlled ventilation, to address the diverse needs of patients with breathing challenges. This adaptability is crucial for tailoring respiratory support to individual patient requirements, which can vary widely depending on the underlying condition and overall health status.

In addition to their ventilatory functions, these devices are equipped with sophisticated monitoring systems that track vital signs such as heart rate, oxygen saturation, and respiratory rate. This real-time monitoring capability is essential for promptly detecting and responding to any changes in a patient's condition, thereby enhancing the safety and effectiveness of respiratory support.

The portability of these ventilators makes them particularly valuable in a range of scenarios, from emergency medical situations and patient transport to home care environments.

2. Literature Survey

In response to the growing number of emergencies such as natural disasters, pandemics, and accidents, there is a critical need for portable and efficient medical devices. Portable ventilators are particularly essential for providing respiratory support in situations where traditional, stationary ventilators are not practical. This literature review explores the functions and effectiveness of portable ventilators designed for emergency use, highlighting their technological advancements, design considerations, and the challenges they address.

The main aims of emergency portable ventilators are to be cost-effective and easy to use. This ensures that they can be widely deployed and operated by non-specialist personnel in critical situations.

A key feature of these ventilators is their compact size and lightweight design. For example, an AMBU (Artificial Manual Breathing Unit) bag-based ventilator weighing approximately 6 kg and measuring 14x7x9 inches exemplifies the ideal design for portability and ease of transport during emergencies. These ventilators are designed to efficiently deliver oxygen to patients using a traditional bag mechanism. Critical parameters such as Breaths Per Minute (BPM), oxygen levels (O₂), and temperature are carefully managed to ensure optimal patient care during emergencies.

Smart automation and control have significantly enhanced the functionality of portable ventilators. The ongoing COVID-19 crisis has emphasized the importance of automation in the biomedical field, leading to a surge in demand for automated solutions. Industrial-grade programmable logic control (PLC) systems aim to control the mechanical ventilation process of large valve emergency ventilators. These systems are often supported by software such as LabVIEW and MATLAB/Simulink for condition-based simulations, particularly for pressure-controlled ventilation.

Maria has analyzed the differences between volume-controlled and pressure-controlled ventilation, showing that pressure-controlled ventilation provides more consistent compensation for the compressible volume of the breathing circuit. Toyama evaluated the accuracy of three different ventilators in delivering small tidal volumes (VT) during volume-controlled ventilation. Additionally, Hussain proposed a Synchronized Intermittent Mandatory Ventilation (SIMV) mode control using a pulse oximeter, which is cost-effective.

The development of emergency-based portable ventilators has made significant strides, driven by the need for efficient, reliable, and user-friendly respiratory support in critical situations. Key innovations such as battery-operated systems, microcontroller-based control, telemedicine integration, and 3D printing have enhanced the functionality, reliability, and adaptability of these devices. Ongoing research and development promise to further improve the capabilities of portable ventilators, ensuring better preparedness for future emergencies. The integration of advanced control systems, automation, and user-friendly designs continues to be at the forefront of making these life-saving devices even more effective.

3. Work Methodology

Developing a low-cost portable ventilator involves a methodical approach focused on affordability without compromising essential functionality. The process begins with identifying critical requirements such as portability, simplicity, and cost-effectiveness. In the design phase, cost-efficient yet reliable components are chosen, including a basic microcontroller (like an Arduino or Raspberry Pi), low-cost pressure sensors, flow sensors, and a compact battery or rechargeable power source. Pneumatic actuators or inexpensive mechanical valves are utilized to control airflow. The prototype is built and tested rigorously to ensure it meets necessary performance and safety standards, with a focus on essential ventilation modes and a straightforward user interface. The device is then subjected to validation and compliance checks with relevant medical regulations. Training is provided for end-users, such as emergency responders, on the device's operation. Ongoing support and maintenance are arranged to ensure the device remains functional and reliable in various emergency scenarios. This methodology ensures that the portable ventilator remains affordable while delivering critical respiratory support effectively.

The work methodology of an emergency-based portable ventilator involves a systematic approach to delivering mechanical ventilation tailored to the patient's needs. The device begins by continuously monitoring vital parameters such as SpO₂ and heart rate using integrated sensors. Based on this real-time data, the ventilator's control system dynamically adjusts key settings like oxygen concentration, respiratory rate, and tidal volume to ensure optimal oxygenation and ventilation. The ventilator operates in various modes—such as volume-controlled, pressure-controlled, or adaptive modes—depending on the patient's condition. Safety mechanisms, including alarms and pressure sensors, ensure the device responds promptly to any deviations from normal parameters, while its portability and ease of use enable rapid deployment in emergency scenarios.

4. Simulation Diagram of Emergency-based Portable Ventilator using Proteus

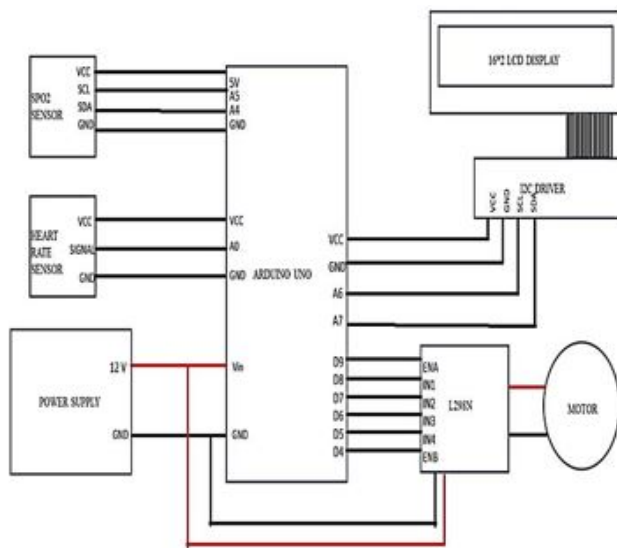


Figure 1: Simulation of Portable Ventilator

5. Prototype Design using Auto Desk Fusion 360

1. Motor Arm:

A motor arm with a length of 280mm, a motor hole diameter of 26mm, and a central curve having a radius of 92mm is a crucial component in various mechanical systems, particularly in robotics and automation. The motor arm serves as a structural element that connects the motor to other components, transmitting rotational motion and torque efficiently. With a length of 280mm, it provides ample space for accommodating the motor and other peripherals while maintaining stability and balance.

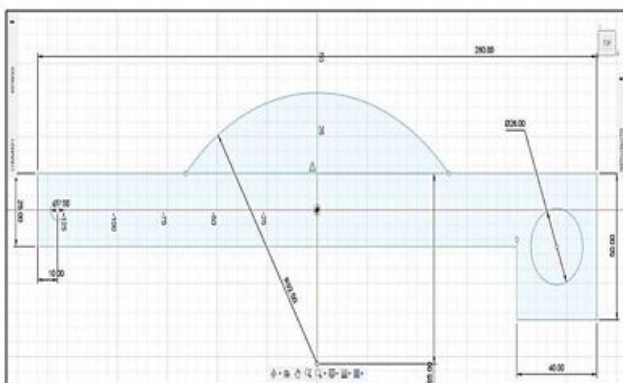


Figure 2: Motor Arm

The motor hole diameter of 26mm ensures compatibility with standard motor shaft sizes, allowing easy installation and secure attachment to the motor. This diameter matches with the motor's shaft, facilitating a snug fit and reliable transmission of rotational motion without slippage or misalignment.

The central curve with a radius of 92mm adds structural integrity and aesthetic appeal to the motor arm. This curved section provides a smooth transition between the motor mounting point and the rest of the arm, reducing stress concentrations and improving overall durability. Additionally, the curved design helps distribute mechanical loads more evenly, minimizing the risk of fatigue failure and enhancing the arm's longevity.

2. Support Arm:

A support arm with a length of 280mm and a central curve having a radius of 92mm is a fundamental component in mechanical systems requiring structural stability and load-bearing capabilities. Unlike a motor arm, this support arm does not feature a motor hole, making it suitable for applications where motor attachment is not required.

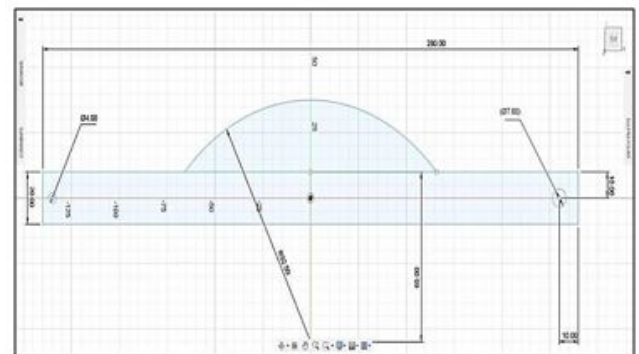


Figure 3: Support Arm

With a length of 280mm, the support arm offers ample space for supporting and connecting other components within the mechanical system. Its robust design ensures structural integrity and stability, effectively distributing mechanical loads and minimizing deflection or deformation under load.

The central curve with a radius of 92mm adds both functional and aesthetic value to the support arm. This curved section provides a smooth transition between different parts of the Overall, a support arm with these specifications serves as a reliable and versatile structural element in mechanical.

A mechanical support arm is a versatile device designed to hold and stabilize equipment, tools, or objects in a fixed or adjustable position across various industries, including manufacturing, healthcare, and photography. These arms are often adjustable, with features like joints, hinges, or telescoping sections that allow for precise positioning. The load capacity of a support arm varies based on its design.

3. Crank:

Crank connecting the motor and the connecting rod is a vital component within a slider crank mechanism, facilitating the conversion of rotary motion into linear motion. This mechanical arrangement is commonly employed in various applications requiring linear actuation, such as engines, pumps, and robotics. The crank serves as a linkage between the motor's rotational output and the linear motion of the connecting rod. It typically features a circular disc or arm with a central pivot point, where one end is attached to the motor shaft, and the other end connects to the connecting rod. With its pivotal connection to the motor shaft, the crank translates the rotary motion generated by the motor into angular displacement. As the motor rotates, the crank moves in a circular path, thereby imparting reciprocating linear motion to the connecting rod.

The connecting rod, in turn, transfers this linear motion to the slider or another mechanism, enabling the desired application. Its length and geometry are carefully designed to optimize the desired stroke length and motion characteristics. Together, the crank and connecting rod form a slider-crank mechanism, which efficiently converts rotational motion into linear motion. This mechanical arrangement finds widespread use in various engineering applications due to its simplicity, reliability, and versatility in translating motion between different domains

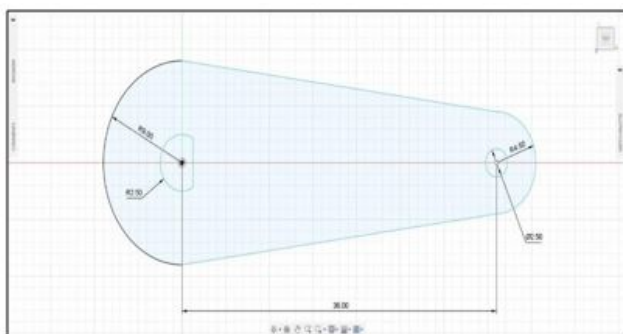


Figure 4: Crank

4. Vertical Support Mount:

A vertical support mount plays a critical role in the structural integrity and stability of a mechanical system housing components such as the crank, connecting rod, and motor within a slider-crank mechanism. This mount serves as a robust framework that holds together and supports the entire assembly, ensuring proper alignment and smooth operation.

Designed to withstand vertical loads and provide a stable foundation, the support mount typically consists of a sturdy base or platform and vertical uprights or pillars. These elements are carefully engineered to distribute the weight of the components evenly and resist bending or deformation under load.

The support mount acts as a central anchor point, securely holding the crank, connecting rod, and motor in place. It provides mounting surfaces and attachment points for these components, facilitating their assembly and integration into the overall system.

In addition to structural support, the vertical mount also plays a role in maintaining alignment and minimizing vibrations or oscillations during operation. It may incorporate features such as precision-machined surfaces, alignment guides, and damping materials to ensure smooth and stable motion transmission.

Typically made from durable materials such as steel or aluminum, vertical mounts are engineered to withstand significant loads while maintaining their structural integrity. These mounts are often adjustable, allowing for fine-tuning of the supported object's height and angle to meet specific operational needs.

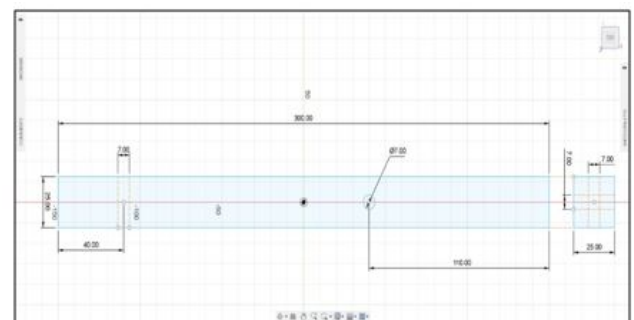


Figure 5: Vertical Support Mount

5. Connecting Rod:

The connecting rod serves as a pivotal linkage within a mechanical system, connecting the crank and the support arm in a slider-crank mechanism. This component plays a crucial role in transmitting motion and force between the rotating crank and the stationary support arm, facilitating the conversion of rotary motion into linear motion.

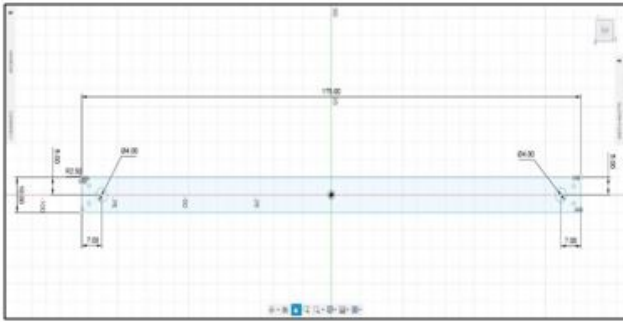


Figure 6: Connecting Rod

Typically, the connecting rod is a slender, rigid rod with threaded ends or attachment points at each end. One end is securely fastened to the crank, while the other end is affixed to the support arm, forming a rigid connection between the two components.

As the crank rotates, it imparts reciprocating motion to the connecting rod, causing it to move back and forth along its axis. This linear motion is then transmitted to the support arm, which may be mounted on a fixed base or frame, resulting in the desired mechanical output.

The length and geometry of the connecting rod are carefully designed to optimize the stroke length and motion characteristics of the slider-crank mechanism. Additionally, the material and construction of the connecting rod are chosen to ensure rigidity, strength, and durability under operating conditions.

6. Horizontal Support:

A horizontal support is an essential structural element within a mechanical system, providing stability and alignment while accommodating the movement of components such as the motor arm and support arm in a slider-crank mechanism. This support serves as a rigid framework that holds the motor arm securely in place and allows the support arm to move freely along its axis.

Typically, the horizontal support consists of a sturdy base or platform and horizontal beams or brackets extending from it. These beams provide a stable foundation for mounting the motor arm and support arm, ensuring proper alignment and smooth operation.

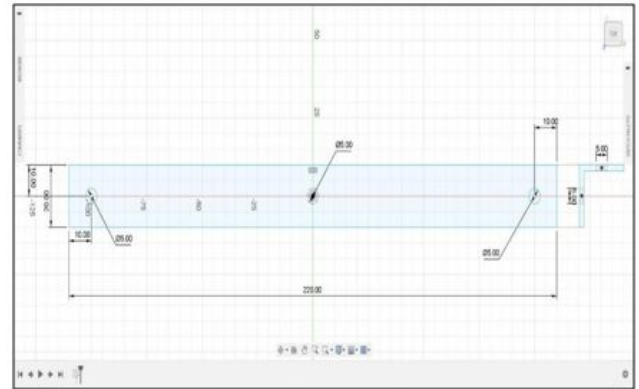


Figure 7: Horizontal Support

The horizontal support is designed to withstand horizontal loads and provide lateral stability to the motor arm and support arm. It may incorporate features such as precision-machined surfaces, alignment guides, and bearing mounts to facilitate smooth and controlled motion. One of the key functions of the horizontal support is to allow the support arm to move along its axis while maintaining stability and alignment. This movement is essential for generating linear motion in the slider-crank mechanism, enabling the desired mechanical output.

Overall, the horizontal support plays a critical role in ensuring the proper functioning of the slider-crank mechanism. Its robust construction and careful design provide the structural integrity and support necessary for the smooth and reliable operation of the mechanical system.

6. Working Model

Component and Design:

A typical emergency-based portable ventilator consists of several key components, including a power source, control unit, user interface, oxygen delivery system, and safety mechanisms. The power source is often a rechargeable battery, ensuring the device can function even in the absence of electricity. The control unit is the brain of the ventilator, managing the airflow, pressure, and oxygen concentration delivered to the patient.

The user interface allows healthcare providers to adjust settings, monitor patient status, and respond to alarms. The oxygen delivery system consists of tubing, valves, and a mask or endotracheal tube, ensuring the patient receives the necessary oxygen supply. Additionally, safety mechanisms, such as pressure sensors and alarms, are incorporated to prevent over-pressurization and other potential risks.

Power Supply and Battery Life:

One of the most critical aspects of an emergency-based portable ventilator is its power supply. These devices are typically powered by rechargeable batteries that are designed to last several hours, depending on the ventilator's usage and settings. The battery life is a crucial factor, especially in situations where access to power sources is limited. Some portable ventilators also come with options for external power sources, such as car adapters or solar panels, providing additional flexibility in various emergency scenarios.

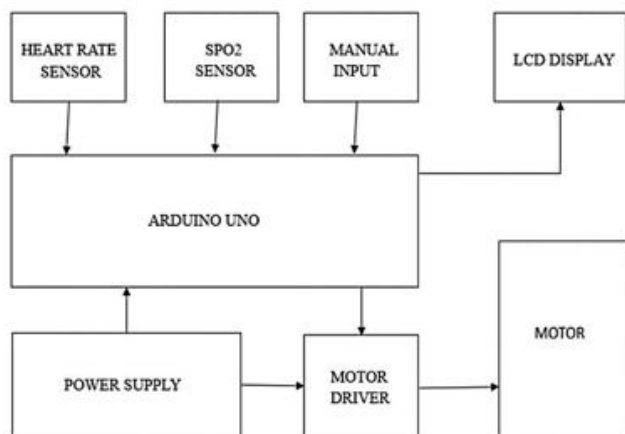


Figure 8: Block diagram

Portability and Ease of Use:

The portability of these ventilators is a significant advantage, making them suitable for use in a variety of settings, including ambulances, field hospitals, and home care. They are designed to be lightweight and easy to transport, with some models even featuring built-in handles or carrying cases. Ease of use is another critical factor, as these ventilators may be operated by healthcare professionals with varying levels of experience. The user interface is often designed to be intuitive, with clear displays and simple controls, enabling quick setup and operation.

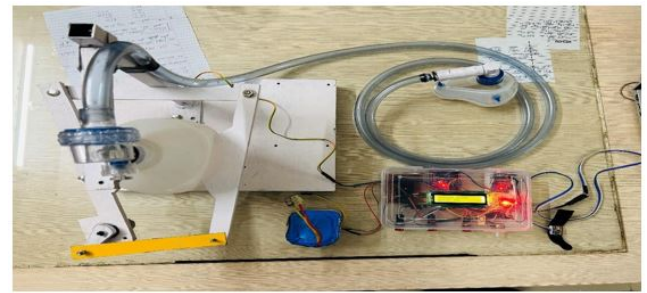


Figure 9: Working Model of Portable Ventilator

In emergency-based portable ventilators, integrating SpO₂ (oxygen saturation) and heart rate sensors enables adaptive, responsive care by continuously monitoring key physiological parameters. These sensors allow the ventilator to automatically adjust settings based on real-time data, such as increasing oxygen delivery if SpO₂ drops or altering respiratory rate if heart rate changes, indicating stress or hypoxia. Additionally, they enable advanced modes like apnea detection, where the ventilator can provide backup breaths if necessary, and personalized ventilation profiles that tailor support to the patient's unique needs. This dual-sensor approach enhances safety, optimizes oxygenation, and improves overall patient outcomes in critical situations.

7. Conclusion

Emergency-based portable ventilators play a vital role in critical care, providing life-saving support to patients in emergency situations. Their compact design, various operational modes, sophisticated control systems, and safety features make them indispensable in scenarios where immediate respiratory support is needed. As technology continues to advance, these ventilators are becoming more efficient, reliable, and accessible, ensuring that patients receive the best possible care, even in the most challenging environments. Their development and deployment are essential components of global healthcare strategies, particularly in addressing the growing need for rapid, effective medical interventions in emergencies.

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