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An Introduction to Low-Cost Portable Ventilator Design

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Abstract— Mechanical ventilation is a life-saver in the development of modern ICUs. This paper provides an idea of origin of modern mechanical ventilators. Based on reviewed literature, a simple, easy-to-use and easy-to-build design of low-cost portable ventilator is proposed in this paper. The proposed ventilator prototype is assumed to have better working performance than already available in market in very low cost. This ventilator will help in the situation like COVID-19 when the whole world facing the difficulties related to ventilators.

Keywords—*Low-Cost Portable Ventilator, COVID-19, Pandemic, Mechanical ventilator, Medical Hardware, Artificial Respiration etc.*

I. INTRODUCTION

Mechanical or artificial ventilators are a life-saving remedy for the patients with acute respiratory failure. It is a very crucial equipment in Intensive Care Units (ICUs), and indeed the rise of its use indicated the beginning of modern ICUs. From more than one decade it has been observed that there is a dramatic rise in mechanical ventilation in the field of both clinical prospective and research after the publication of revolutionary article by ARDSNet investigators in New England Journal of Medicine about the significance of lung-protective ventilation strategy [1]. For interested readers it is better to mention that there is a lot of literature which gives detailed information about the mechanical ventilation and emphasis of ventilation induced lung injury (VILI) [2-7].

In second century (A.D.) a distinguished Greek scientist and physician Galen played an important role by introducing the anatomy (structure) to understand the diseases [8]. According to him the respiratory system of animal and human is same and responsible for circulating system in human body. His postulates also indicates that according to him the phenomena of breathing is responsible for heart to beat.

During the Dark Age era there was no significant improvement in the field of mechanical ventilators nor in the field of science. But in mid-16th century Andreas Vesalius changed everything. He also suffered the anger of church due to his research and findings for using human remains and cadavers. His many findings contradicted the Galen's theory about human respiration system. In 1543, he published his finding in the form of a brilliant dissertation entitled "De Humani Corporis Fabrica" which is the actual base of today's positive pressure ventilators [9].

Since late 19th century to 1950s negative pressure ventilators were introduced. In this technology the ventilation is provided using negative pressure or less pressure than atmospheric pressure brought around the patient's body to replace or increase the work being done by the respiratory muscles.

In 1864, the first such body enclosing devices was designed by Alfred Jones [10], in which the patient is made to sit in the box. The box pressure was reduced by a specially designed plunger which caused inhalation; the reverse produces exhalation. This ventilator designed cured many diseases like neuralgia, paralysis, seminal weakness, bronchitis, asthma and dyspepsia etc. In 1876, another scientist Alfred Woillez invented the first working iron lung "Spirophore"[11]. Wilhelm Schwake invented pneumatic ventilator in 1926 that particularly concerned with breathing pattern of patient.

The recovery from polio proved to be watershed for artificial ventilators. Before that ventilators were considered not much useful for treatment. In summer 1951, an international conference on polio held in Copenhagen which was attended by many world polio experts. In this conference it was came to light that there was a terrible polio epidemic caused by polio virus. It was recorded more than 50 patients admitted due to this disease every day in Infectious Disease Hospital of Blegdams, many with bulbar paralysis and disorder of respiratory muscles. The mortality rate was exceeding >80%. Bjorn Ibsen, an anaesthesiologist discovered that the reason is respiratory failure not renal failure. Due to this finding the motility rate suddenly dropped to 40% from 80% overnight [12]. Since 1950s to present the positive pressure ventilators are used in ICUs.

In India after February 2020 the need for ventilators increased for the treatment of COVID-19 patients. In the situation like COVID-19 not only India but the whole world is facing the shortage of ventilators. India have approximately nineteen lakh hospitals, ninety-five thousand ICU (Intensive Care Unit) beds, and forty-eight thousand ventilators only but the population of India is approximately 135.26 crores which indicates that there is a huge shortage of ventilators.

There are many complications with existing ventilators like easy to hyperventilate patients and limited ability to gauge tidal volumes, common problem of poor seal in one-handed CE grip, gastric swelling, aspiration, exhaled secretions and moisture, risk of barotrauma, claustrophobia, incorrect assembly etc. [13].

The cost of ventilators in India is more than 1.5lakh which is very expensive and an obvious one of the reasons for not having sufficient quantity of ventilators in every hospital.

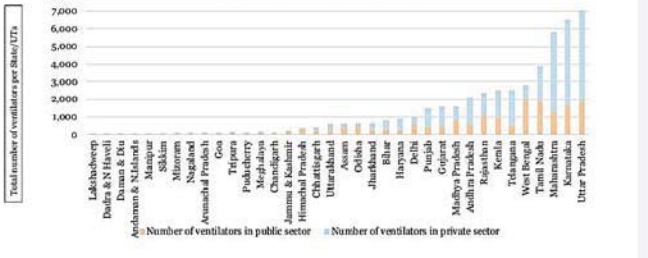

Fig 1: This graph showing the total no ventilators per states in India [14].

This low-cost portable ventilator delivers breath by compressing the Ambu bag or generally known as a manual resuscitator or self-inflating bag, with the help of motor drive mechanism means it will we operated without human.

This machine supports 500-600ml tidal volume with a continuous working ability for several days it will provide 12 Respiratory rate (RR/min) that can provide required amount of tidal volume for pneumonia patient.

This paper provided a solution to tackle the shortage of ventilators by introducing the low-cost portable ventilators. This Low-Cost Portable Ventilator is inexpensive and reliable device that can be used to replace bulky and expensive hospital ventilators. These ventilators can be brought by an individual or by small clinics in much cheaper cost and can be stored in a shelf of almirah. There are many advantages of these kind of ventilators like, this does not need a specialized person to operate etc. [14].

II. COST FACTOR

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The functionality of the ventilator increases with the increase in cost. Fig 2. Clearly defines the huge difference in cost of mechanical ventilators from manual to full functional hospital ventilators. It is very unfortunate to get manual ventilator system if the cost is compromised. That causes swelling in the hands of person who is pressing the ambu bag manually in few hours. The middle segment of the graph incorporates the current compact ventilators which can be extensively classified as electric and pneumatic. Packed gas energy is being impelled to use in Pneumatic ventilators, frequently a standard 50psi (345kpa) pressure source regularly accessible in clinics.

But, to create consistent ventilation for pneumonia cases, for example, COVID-19 patients a computerized what's more, ease Ambu pack wind stream framework is powerful to spare life [16].

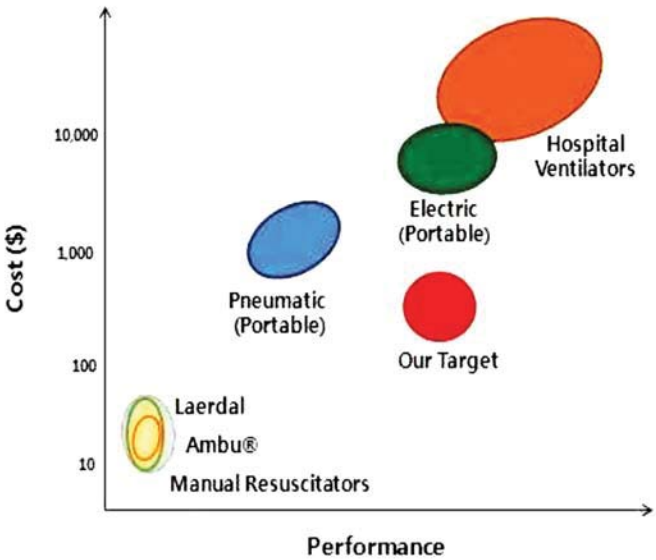

Fig 2: Chart showing cost-performance distribution of ventilators [16].

III. WORK METHODOLOGY

An Arduino Uno based motor drive of clockwise and will provide the required motion for the arm movement to maintain air flow with a controlled volume and pressure rate [17].

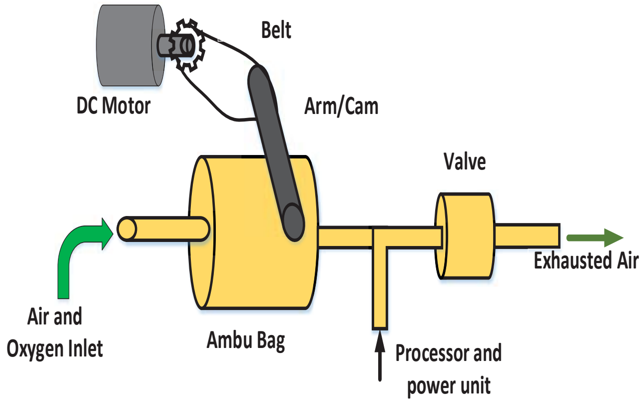

Fig 3: A sketch of working process of proposed prototype.

IV. DEVICE DESIGN

Air Delivery System: Air delivery system identify two main routes. It uses a source of pressure from time to time to bring air while another brings breath pressing the air reservoir. The last method accepted as eliminating the need for a positive pressure source to operate continuously. This decreases energy requirements, as well as the need to fix parts of the air for difficult and costly things.

Where most of the ventilators are emergency and portable they are all designed for mechanical customization parts, we have chosen to take orthogonal approach build on affordable BVM, very simple existing technology volume migration performance respirator. Because of their large volume production and simple design, BVMs less expensive (about $ 10) too they are often used in ambulances and hospitals. And they are easily found in countries which are in developing state. Accoutre within air cushioning total and comprehensive valve system, provides natural and basic requirements needed to get respirator.

The biggest problem with is their documentation operation that requires a continuous operator engaging in squeeze the bag as well as holding the mask to the patient. This process works causes enervation during prolonged work, too effectively restricts the adequacy temporary relief from these funds. In addition, inexperienced operators can potentially harm the lungs of a patient by overdoing the pressure of the bag. Therefore, a machine had to be designed to use BV M. This path leads to an inexpensive machine to provide the foundation operation required by mechanical respiration levels [18].

A. Compression Mechanism: The most pronounced ways to use BVM to do that mimic the moment of the hand that was in the bag built. This requires the use of a line operating modes (eg pinion and lead screw or rack) which although easy to that use, need straight bears and more space. There were other ways of oppression available to take advantage of the cylindrical condition of BVM. Whoso as BVMs are designed according to the labor, their exterior is pressed faces are made of materials with high contrast to keep the touch of the hand smooth. This removes the belt tightening option wrapped in a bag as an actuation. Avoiding problem associated with height face-to-face conflict, two major baptism candidates the performance was cam and chain pressure. This kind of options use skipping contact with the wallet is preferably smooth, to eliminate loss due to collisions between the actuator and the bag [19].

V. PROTOTYPE DESIGN

First Prototype Design: ln the sense of the cam selected as the best BVM compression method, initial prototype is designed for power requirements and to measure strength . The closure frame contains 4-dimensional segments of 12.5 mm clear lucite, each laid on the floor a frame category with interacting partners. The tool is easily cut with a laser and allows the appearance of internal parts. Two the inner sections (ribs) have U -shaped sections formed alignment with the upper BVM mountain, while end stages include openings for seating BVM oxygen storage area and valve neck. The dynamic cam assembly which is mounted over an aluminum cover with hinges, two 2.5 " shaped parts (63.5 mm) attached to an 8 mm aluminum shaft mounted on nylon bushings were also included [20].

Second Prototype Design: The second version is built where all the files for moving objects moved within fenced. Installation size added to adjust the width of the era arm, and making car space, microcontroller battery pack. The enclosure of the fenced area, and one unit hinges from the side in order to lower the top of the acrylic bag better. Potentiometer was assembled at the end of the battlefield to be used as status response sensor. Figure 4 displays the isometrical view of the second CAD model [20-23].

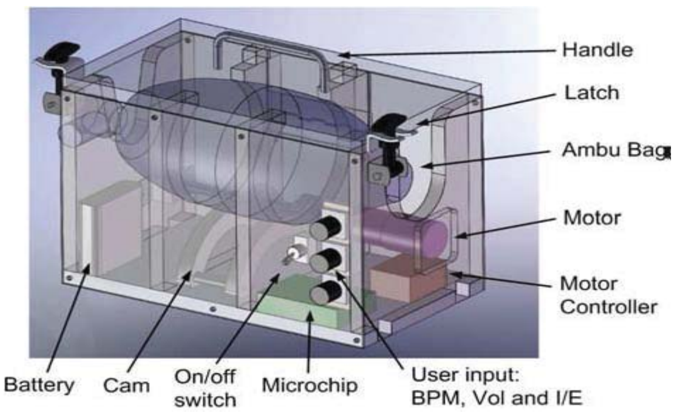

Fig 4: CAD model of Prototype from literature [18].

VI. CONTROL IMPLEMENTATION

Control Design: This wind turbine gives reliable waves volume using the help-control mode (AC). In the patient, the operator selects the acceptable wave volume, usually 6-8 mL / kg of suitable body weight and low respiratory rate. This it offers a little guaranteed air (Ve). lf the patient breathes more than a set Figure 5: Volume vs. Camera angle Figure 4: Second CAD model average, negative stimulus pressure excel. The 2cm H20 machine causes the respirator to deliver volume of water set. The beauty of the AC mode is that the patient has a guaranteed minute ventilation for acceptable gas exchange of the assembly physiological requirements. What's worse if the patient has a rapid breathing or tachypneic, respiratory alkalosis pay occur to improve and for those with obstructive influence, pulmonary disease, shortness of breath might occur, increase intrathoracic pressure with intrathoracic pressure an unpleasant hemodynamics and Gas Exchange Results. These problems however, are usually addressed with a reduction of breathing rate and relaxation where needed. The AC mode, one of the most commonly used ventilation systems, is adequate to handle most respiratory failure conditions in clinics. This air machine knows used for intubated patients with endotracheal tube anyone who will get illegal mechanical cooling using a mask often used for the provision of continuous air flow (CPAP) [24].

Parameters: The operator adjusts the frequency and promoting the expiration rate using through continuous analog buttons are attached to without air. The water volume range of 200-750 mL and 5-30 minutes of breath is a standard (bpm). This confirms the low pressure air of 21L and a minimum of 1.5L Still, these numbers do not merely represent the limits of the settings for the final design model type. Theoretically, respirator is capable of delivering anywhere up to 60 Litres/ minute volume capacity. Although, this is not practically tested. Average A: E was not included in this model but in theory it can be the desired width with proper limits determined by other parameters. In final build width will be determined in deliberation with respiratory professionals so that it allow secure settings in wide range [25].

Controller: The microcontroller board is selected to power our system from the Arduino Duemilanove shelf. To achieve user-defined performance microcontroller works in a simple way control loop. The control loop is caused internally timer set for user put, and promotions side started at the beginning of the loop. When the right amount of water reached, then The actuator returns the cam to the camera, the original position and hold until the next wind. The loop takes in the occasional breath again. Whenever a loop is broken by a breathless patient attempt (feel pressure sensation), a rapid respirator brings air, loop and reset timer. This diagram shows control loop ventilator in Fig 6 [26].

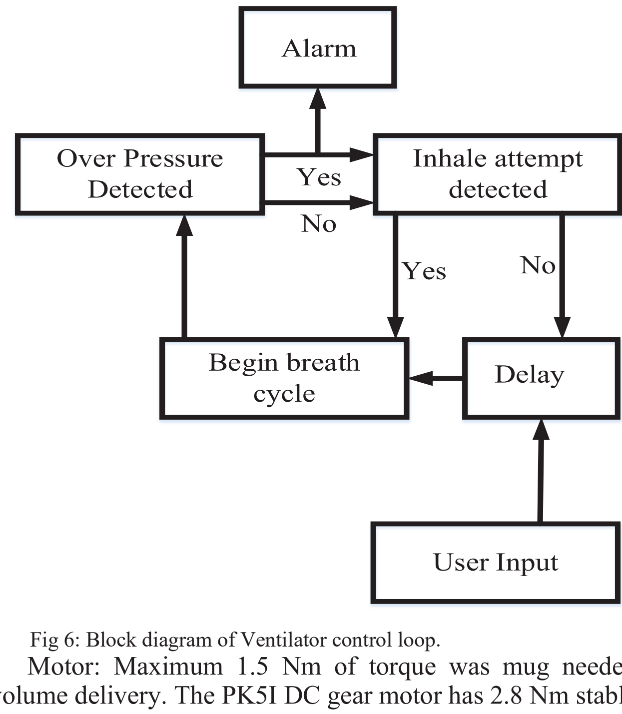

Fig 6: Block diagram of Ventilator control loop.

Motor: Maximum 1.5 Nm of torque was mug needed volume delivery. The PK5I DC gear motor has 2.8 Nm stable table selected for example

Despite the low torque rate measured in the test, we found that the engine did not successfully provide sufficient torque to drive the cam while slowly breathing cycle levels allocated to other patients

. While a larger motor will have to accomplish better to properly control the speed, this car worked in an acceptable way Figure 6: Air control loop in the field of conceptual evidence. lt was desirable with an operating speed in the required range of 50- 70 per minute and its gear depletion ratio of 51: 1 [26].

Motor driver: It has two H-Bridges regions. On opposite sides these two H-Bridges direct through motor, depends upon set of switches in correct circuits is enable. Pwm pin indicates the speed of the car. Battery delivers Power directly, so that only battery capacity and current limit chip. We have chosen the solarbotic car driver, which is able of moving 5 amp of current in given two circuits. Car table PK5 I lt is currently rated at 5.20 amps which means that the driver of the car will be capable to handle system specifications properly.

User Interface: There are three user inputs (bpm, wave volume, and 1: E ratio) set by three potentiometer terminal. Future device times included will be the addition of a LED display to display air pressure level and input settings too battery power status.

Safety Features: Air pressure is considered by pressure sensor connected to the sensor output in BVM for ensuring that the patient is not harmed. If the pressure too high the same pressure sensor as the pressure sensor used by the start of helping alarm triggers power which warns the doctor care for the patient. As an alternative to safety prevent excessive exaggeration, future calculations consolidate the pressure relief valve of the unit [27].

Power Delivery: Ventilator can directly power by the AC / DC converter from a wall or inverter for your engine. lf extraneous electricity is not available, the respirator run on any battery it can to deliver I 2- 15 volts at minimum of 3.5 Amps. Because for example, we need four cells, 14.8 volts, pack of Li-ion batteries which is capable of 4.2 Amps (rated with strong cycles) and of volume 2200 mA-hr [28].

VII. CONCLUSIONS

In this paper a low-cost portable ventilator designed is introduced with the help of suitable drawing and control loop diagram. The proposed low-cost portable ventilator is an inexpensive alternative to the exorbitant purchasing cost hospital ventilators. The proposed ventilator can provide 500-600ml tidal volume with a continuous working ability with 12 RR/min that is sufficiently high for a pneumonia patient.

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