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Design And Prototyping of Emergency Mechanical Ventilator

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***Abstract*— This paper describes the design and prototyping of portable low-cost mechanical ventilator that is use for worst condition such as COVID-19 and in far remote places with limited available resources. The ventilator. The ventilator takes air inside BVM and pressing the valve of the common bag valve (BVM) with the arm, removing the need for a personal BVM user. The prototype is made of wooden sheet, imitation 10.04 x 10.04x 14.5 inches (255x 255x 368.3mm) and a weight of 4.3 kg. It is driven by a Wiper Motor of Skoda Octavia with 14-watt power rated 13.5 V voltage and features an adjustable discharge of oxygen. Discharge of required volume as per breaths per minute with is adjustable via user friendly knob and setting are displayed on LCD screen. Future modification will be improved to use less energy and it will continue to do so designed for construction and integration with new AI features. From this prototype the arm actuated BVM compression strategy proves to be an effective way to achieve low cost, low-power ventilator technology that provides key ventilator features in place.**

I. INTRODUCTION

As we know it is the COVID-19 epidemic, which has devastated the world by 2020 by spreading unprecedented numbers and causing tens of thousands of deaths in a few months. The death toll has risen sharply in districts where the number of patients in need of hospital care is greater than the availability of care. Many patients with COVID-19 develop Acute Respiratory Distress Syndrome (ARDS), a condition that can be treated with mechanical ventilation. The global medical community is currently facing a severe shortage of medical equipment to deal with the COVID-19 epidemic. In particular, this is the case for ventilators, which are required during COVID-19 treatment initially, during the intensive care phase and during the extended recovery period. In response to the need for mechanical ventilators, they have designed and tested an emergency ventilator (EV) that can control the patient's upper respiratory pressure (PIP) and breathing rate, while maintaining end-of-breath pressure (PEEP). Companies are increasing production, but this will not be enough to meet demand according to current forecasts. The COVID-19 emergency highlighted the need for research in Evs. In general, there is a shortage of peer-reviewed articles explaining the science and engineering of EV design and performance, and there is a need for new research on EV design, performance, and testing. Patient management during COVID-19 is prone to serious lung injury problems, and ventilators should be able to deal with conditions of rapidly changing lung compliance, possible collapse and consolidation. So as a general concern of any ventilator design ventilator driving pressure is an important factor in a patient’s comfort. Patient management during COVID-19 is prone to serious lung injury problems, and ventilators should be able to deal with conditions of rapidly changing lung compliance, possible collapse and consolidation.

COVID-19 (Coronavirus disease 2019) has become global world pandemic with exponential growth rate. The virus is manifests commonly with little or any symptoms, but can also lead to a rapidly progressive fatal pneumonia of infected. Up to (October 2020), COVID-19 reaches 2,98% mortality from all infected subjects. In general, the process of mechanical ventilation controls a flow, volume, and pressure of air and gases to a patient´s lung. Artificial Lung Ventilation (ALV) represents the respiratory system. The respirator provides gas flow through the respiratory system. ALV is either used for short term or long-term support for patients with serious damage of their respiration system. From the clinical point of view, ALV is support with potential risks and complications, which need to be known in order to get suitable clinical results. Study from 2013 declares, that it is estimated, that ALV is required by roughly 1.5 million of patients in United States every year. According to the researchers, the mortality of patients undergoing ventilation during critical disease is 31–37%. A decision to use ALV is based on several factors and should be carefully evaluated. The rough factors are evaluation of parameters of oxygenation, ventilation, lung mechanic, and condition of infected person. However, very significant is evaluation of past condition as well as supposed progress of patient condition. This concept seems to be more relevant than simply examining the parameters of the physical indicators. Each patient is unique and its condition can be specific, and therefore, ALV should be optimized according to patient´s lung mechanics. Thus, a ventilator is a machine that uses mechanical ventilation to help patients breathe and provide oxygen when their own body is not able to do this correctly. The first widely used ventilators were during the polio epidemics,1920s and 1930s, and called iron lungs. These were large noninvasive devices that required most of the patient’s body to be in a box. Then it used negative pressure to expand/contract the patient’s chest and thus also the lungs, drawing air in/out.

A low-performance ventilator is one of the simplest, low-cost, and low-level hospital ventilator ventilators during ventilation. There are a variety of low function ventilators that are commercially available, with different ventilators designed for different applications and intended to satisfy the requirements of those applications. An automatic resuscitator is a device that can replace a handbag to provide oxygen to a patient who has stopped breathing, a portable respirator or ventilator that can take air out of the hospital or during transport, and an emergency respirator or emergency ventilator. there are patients who need a ventilator but a hospital-level respirator is not available. Although low-performance ventilators are all less efficient than conventional hospital-level ventilators, they may be attractive in some situations where low-cost features, convenience, and accessibility are important. We refer to this research device as an emergency ventilator or EV, because it is intended for use in an emergency and because it reflects the spirit of the animal using the device.

The Portable Ventilator is a mechanical ventilation device designed to tackle one of the biggest problems with current ventilators, their restrictiveness. Currently patients are required to either be hospitalized and occupy an ICU room risking contracting disease or forgoing care. This leaves many patients with milder symptoms to have two bad options. Along with this, hospitals are also at a loss. Every patient with milder symptoms that is hospitalized is one less ICU room available for other patients with more severe symptoms. This also puts a strain on the limited resources hospitals have, such as nurses, since the ventilator must be constantly monitored and adjusted.

The Portable Ventilator seeks to solve these problems by providing a third option to patients and hospitals. This is the ability to provide out-patient care for mild cases that require help breathing and oxygen intake. This would be done by designing the Portable Ventilator to be lighter, smartphone compatible, automatic monitoring and adjustment, and a simpler interface for controlling the device. This would allow the ventilator to be used at the patient’s home with no need for professional monitoring. This would meet both the patient’s need to be provided care without hospitalization and the hospital’s need to keep available rooms and staff.

II. CONCEPTUAL DESIGN AND WORKING

A. Air Delivery Techniques

Two major strategies were identified ventilator air supply system. One strategy uses a constant pressure source to periodically move the air while the other moves the air pressing the air reservoir. The last method accepted as eliminating the need for this continuous operation of positive pressure source. This reduces energy requirements as well expensive and difficult to fix parts of the air.

Although very urgent and practical ventilators are all customized machine parts, we chose to take orthogonal method - by building on Cheap BVM, available technology available is a simple illustration of a volume ventilator. Because of the simplicity of their design and mass production volumes, BVMs are very cheap and frequently used in hospitals and ambulances. They are ready too found in developing countries. Installed air reservoir and complete valve system, naturally they provide the necessary basic necessities for ventilation.

The biggest drawback with BVM is that manual operation that requires a continuous operator sharing squeeze bag. This works the process causes fatigue during prolonged work, and effectively restricts the use of this temporary relief funds. In addition, untrained the user can easily injure the patient's lungs by over the pressure of the bag. Our way, therefore, it was to design a working machine to Exchange BVM shares. This approach leads to an inexpensive machine that provides basic materials operation requires mechanical ventilator standards.

B. BVM Actuating Mechanism:

BVM compression can be achieved with line functionality (e.g., lead screw, rack and pinion or crankshaft), radial actuation (e.g., noose), or rotary actuation (e.g., camera). Line formation the idea is quickly rejected because it required linear bearings add extra cost, complexity and quantity in the actuator. Radial the concept of congestion was tested but found to be so ineffective. This is because the bag has a high external friction so the pressure belt does not slide easily over the ground. This could be fixed with a rolling chain instead of a belt. However, rollers present such new problems as itching. The bag is also not designed radial actuation and such operation are productive instability leading to non-linear pressure. In contrast, radial performance as achieved by the camera mimics hand movements when bagging built. It is an integrated and functional design wrap up contact with the bag, thus minimizing conflicting losses between the actuator and bag. So, the idea was followed.

C. Arm Concept:

The arms are design in such a manner as it fitted the ambu bag (BMV) entirely into it. As BVM compression is required in proper and smooth way, the arms are constructed with the crescent shaped which helps for efficient compression. Due to the motion of arm, smooth, repeatable deformation is achieved and hence ensure constant air delivery. By controlling the speed of the motor, the amount of air delivered per minute can be controlled.

D. Design Consideration:

For the prototype device, a self-inflating bag squeezer Ambu bag is used. Parts of the device can be mass-produced at low cost during an emergency such as an epidemic, where more expensive conventional ventilation equipment may not be available at a sufficient price to deal with a large number of patients. The device was also constructed to evaluate the test lung model and is capable of delivering nitric oxide (NO) in the breathed gas.

Design considerations:

The main considerations for designing a portable mechanical ventilator:

1. Medical: user-specified breath/min, insp./expr ratio and tidal volume; assist control and positive end expiratory pressure (PEEP); maximum pressure limiting, humidity exchange; infection control; and limited dead-space.

2. Mechanical: portable; standalone operation; robust mechanical, electrical, and software systems; readily sourced

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and repairable parts; minimal power requirements; and battery powered.
3. Economic: low-cost.
4. User interface: alarms for loss of power, loss of breathing circuit integrity, high airway pressure, and low battery life; settings and status displays; and standard connection ports.
5. Repeatability: indicators within 10% of correct readings and breath frequency accurate to one breath per minute.

With consideration of mechanism which ensures a gas flow through a respiration system during breathing, there are four groups of artificial ventilation, namely positive pressure ventilation
(PPV), negative pressure ventilation, jet ventilation, and high-frequency ventilation. A ventilation mode is defined by control algorithm, which is based on information about pressure and/or gas flow through a ventilator. Considering the gas motion direction, it is possible to divide a respiratory cycle to the following four phases.
1. Inspiration phase - An activity of ventilator is controlled by some control parameter like pressure or gas flow. In the next process of inspiration phase, the ventilator is limited for pressure or gas flow increase. Once the condition of limitation has been fulfilled, the ventilator leaves an expiration valve closed until inspiration phase does not finish. Then the ventilator continues to an inspiration pause or directly to an expiration phase.
2. Inspiration pause - Standstill of gas flowing through an airways and intrapulmonary redistribution of tidal volume is in a progress. By applying of inspiration phase, a distribution homogeneity of ventilation should be improved.
3. Expiration phase - From the view of ventilator, this is a passive phase of respiratory cycle. An exhalation is achieved by expiratory muscles of patient.
4. Expiration pause - A phase started by ending of air flowing from patient up to next respiratory cycle, which starts with inspiration phase again.

E. Prototype Design:

The prototype design of low weight and easy portable mechanical ventilator is developed by the application of SOILDWORKS, which can help to treat patients in any emergency conditions at any place, in any university, institution and at home as shown in fig (1). It works on principle of Crank mechanism the device is actuated by compression of arms via crank mechanism, which helps in having the contact along the surface of the self-inflating bag valve mask (BVM) as shown in fig. (4) and thus stimulate the expiration and inspiration process. Within BVM all the required safety devices and valve are present.
The design consists of crescent shaped arms mounted on main supporting frame mounted on base plate. The arm is then connected to wiper motor. As motor rotates, it compresses and expands the BVM bag to develop the gas delivery in more efficient manner with low power requirements and ensure

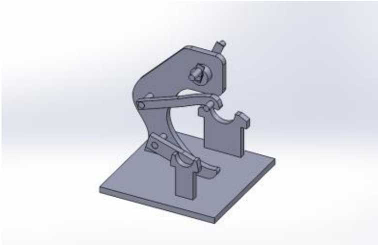

Fig. (1) Solid work Assembly of Emergency Mechanical Ventilator.

constant air delivery. As motor can regulates on three different rpm, it helps to control air volume delivered. The fully opened annotated 2D design drawing of mechanical ventilator with the dimensions of components are selected specifically to make least possible space as shown in fig (1).

III. COMPONENTS AND SPECIFICATIONS.

A. Arduino:

Arduino UNO is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. This board can be connected to other Arduino boards, Arduino shields, Raspberry Pi boards and can control transmission, LEDs, servos, and motors as output. Arduino is used to control the engine by default. Arduino boards can read input - light sensor, finger button, and convert it into output.
Specifications :
Input Voltage : 6-20V
Operating Voltage : 5V
Digital I/O Pins : 14
Analog Input Pins : 6

Fig. (2) Arduino

B. LCD Display:

16x2 LCD means it can display up to 16 characters per line and there are 2 such lines. This LCD has two registers, namely, Command and Data. LCD (Liquid Crystal Display) is a type of display that uses liquid crystals in its operation. Here, we will receive the serial input from the computer and upload the drawing to Arduino. The characters will be displayed on the LCD.
Specifications :
Number of columns : 16
Number of rows : 2
LED color : green
Operating Voltage : 4.7-5.3V

Fig. (3) LCD Display

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C. Ambu Bag or Bag Valve Mask (BVM) :

The Ambu bag is a hand-held device commonly used to provide positive pressure ventilation to patients who are not breathing or not breathing adequately. It is used for controlling the machine by doing the functions of contraction and expansion. The average capacity volume of Ambu bag is 1600 ml.

Specifications :
Material : Silicon
Capacity : 1600 ml
Size : 15mm inside / 22mm outside diameter

Fig. (4) Ambu Bag

D. Wiper Motor:

Wiper motors are generally rated 12 volts or 24 volts and sometimes maybe 6 volts. In most cases, we need to decide between 12V and 24V. This will help us to determine the kind of motor that suits our wiper system. Wiper systems generally use two wipe speeds to suit the conditions and also an intermittent wipe facility is incorporated. A wiper motor on a modern technology should be a high-powered quiet unit operating on a current of 2 – 4. Wiper motors will probably not exceed 50 watts (4.2 amps on 12 volts). A 30-amp motor will require 360 watts and will probably produce at least 250 watts of mechanical power.

Specifications:
Motor Voltage : 12V
Speed : 45 RPM
Power : 14 watts or HP
Rated Voltage : 13.5 V
Current no load : 1.5 A

Fig. (5) Wiper Motor

E. IR Sensor:

An infrared sensor is an electronic device used to sense certain aspects of the environment. It does this by emitting or receiving infrared radiation. Infrared sensors are also capable of measuring the output of an object and detecting movement.

Specifications :
Operating Voltage : 5V DC
Range : 20cm
Supply Current : 20mA
I/O Pins : 3.3V & 5V

Fig. (6) IR Sensor

IV. METHODOLOGY

The designing aspect of the Ventilator machine is based on the process of compression and expansion, that is the key aspect to be considered while implementing the Ventilator machine. These techniques of compression and expansion is for Ambu bag.

The design can be broken into three main parts:
i. The breathing circuit,
ii. The mechanical ventilator and
iii. The controls.

Breathing circuits are the ones which hospitals already have as in the pump to reach out.

We will make use of Ambu bag as it is the most important part, which is also like a manual respirator.

It can be squeezed by any trained medical person to provide the air that can be pushed into the lungs temporarily.

Fig.(7) Assembly

The motor which we have used for controlling purpose is the Skoda Octavia Wiper motor and its corresponding linkages leads to contraction and expansion. In this case, the Ambu bag is doing the functionality if both Compression and Expansion. We have created a Jaw in which the Ambu bag is fitted

purposely. This will eventually help the motor to perform the necessary actions of compression and expansion. The challenge which we are facing is actually the wholesome process. The motor basically follows a 3-stage working. Stage1, we can distinguish as a slow mechanism, stage2 as a moderate or fast and correspondingly stage 3 can be ultra-fast mode. Basically, to perform this, we have 3 speeds for that case differently.

V. CALCULATIONS

Discharge:
Volume of 1 Ambu bag=1600 ml
Compression ratio of the Ambu Bag = 75% =0.75

Motor RPM=45

STAGES:
Stage1= 35 rpm
Stage2: 40 rpm
Stage 3: 45 rpm

Final Discharge= Ambu bag volume x Compression ratio x RPM …... [unit: (mg/liter)]

Stage 1:
Final Discharge= Ambu bag volume x Compression ratio x RPM
Final discharge= 1600 x 0.75 x 35
= 42000 mg/liter
Stage 2:
Final Discharge= Ambu bag volume x Compression ratio x RPM
Final discharge= 1600 x 0.75 x 40
= 48000 mg/liter
Stage 3:
Final Discharge= Ambu bag volume x Compression ratio x RPM
Final discharge = 1600 x 0.75 x 45
= 54000 mg/liter

Discharge fluctuates as the O2 level fluctuates. It is in direct proportion.

VI. OUTPUT

The motor will rotate at three different rpms and will perform the necessary compression and expansion action. This whole process is manually, so in order to make it more efficient and to get more accurate results we have made the entire process automated by using Arduino Nano along with infrared sensors. Arduino Nano will help to digitize it and make and change the process automatically. It will detect the pulse rate automatically and in the same way the machine will change and give output in accordance with it. These pulse rates will be visible on the 16*2 LCD display. Basically, its task will be to calculate human being's pulse rate and necessary compression and expansion should work.

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