Design of Efficient Low-cost Ventilator for Emergency COVID19 Patients

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Abstract

We propose the design of a ventilator which can be easily manufactured and integrated into the hospital environment to support COVID-19 patients. The unit is designed to support standard ventilator modes of operation, most importantly SIMV-PC (Synchronised Intermittent Mandatory Ventilation) mode. The design is under prototyping stage.

Motivation.

The worldwide medical community currently faces a critical shortage of medical equipment to address the COVID-19 pandemic [1]–[3]. In particular this is the case for ventilators, which are needed during COVID-19 related treatment at onset, during the intensive care phase and during the very extended recovery times. Companies are scaling up production [4], but this will not be sufficient to meet the demand according to the current forecasts. There is a wide spectrum of devices, ranging from highly sophisticated through to simpler units [5], [6] useful in the milder phases of illness. Amid pandemic crisis in India we were motivated to cater the local shortage of this medical equipment and develop a somewhat semi-automatic mechanical ventilator that could be used in emergency medical units in hospital as well as mobile medical units such as ambulances to provide emergency ventilation using an Ambu bag based setup to patients affected with COVID-19.

Modes of Operation; overview.

Patient management during COVID-19 faces serious issues of lung damage, and the ventilators must be able to handle situations of rapidly changing lung compliance, and potential collapse and consolidation. Thus as a general concern for any ventilator design the driving pressure of the ventilator is a crucial factor for patient comforts. In particular, when a low tidal volume is used, the driving pressure is an important variable to be monitored to assess the risk of loss of the patient breaths. In light of the extreme importance of the pressure monitoring, the ventilator will target pressure-controlled modes. This will include: PRVC (Pressure Regulated Volume Control) mode, SIMV-PC (Synchronised Intermittent Mandatory Ventilation); and in addition, a basic mode of operation: CPAP (Continuous Positive Airway Pressure). Synchronized intermittent mandatory ventilation (SIMV) is a type of volume control mode of ventilation. With this mode, the ventilator will deliver a mandatory (set) number of breaths with a set volume while at the same time allowing spontaneous breaths. Spontaneous breaths are delivered when the airway pressure drops below the end-expiratory pressure (trigger). The ventilator attempts to synchronize the delivery of mandatory breaths with the spontaneous efforts of the patient. In contrast, to assist control ventilation (ACV), SIMV will deliver spontaneous volumes that are 100% driven by patient effort. Pressure support (PS) may be added to enhance the volumes of spontaneous breaths. SIMV was initially developed in the 1970s as a method to wean patients who are dependent on mechanical ventilation.[7] SIMV gained popularity and was the most widely used ventilatory mode for weaning, with 90.2% of hospitals preferring SIMV in a survey conducted in the 1980s.[8]

Our proposed ventilator is also capable of Advanced Synchronized intermittent mandatory ventilation (SIMV) mode and a basic non-invasive operation mode where a fixed pressure is made available to the patient. Our design also provides PEEP (Positive End-Expiratory Pressure), which is not a ventilatory mode in itself but is designed to support steady low positive pressure to the lungs.

Although international definitions vary, this corresponds to the CPAP definition from the MHRA documentation [9]. In all modes of operation, PEEP will be available, which is important for patient management to avoid alveolar collapse. Note that the ventilator design outlined here is not intended to replace the high-end devices needed for the most intense phase of treatment, but should be appropriate and useful in the hospital environment for milder symptoms or long term care and recovery.

Conceptual Design and working

We describe here the conceptual layout of the system. The targeted modes of operation, as explained above, are principally SIMV and CPAP along with PEEP. The design has the patient safety built-in as a priority, so that all failure modes revert to a situation which prioritises patient safety. In particular, if the patient stops breathing in pressure support mode, the ventilator shifts automatically onto mandatory ventilation. The conceptual schematic is shown in figure 1. The unit takes as input the standard compressed or mixed air supply available in hospitals, in such a way that one supply could be connected to several units. We expect that typically the pressure supplied will

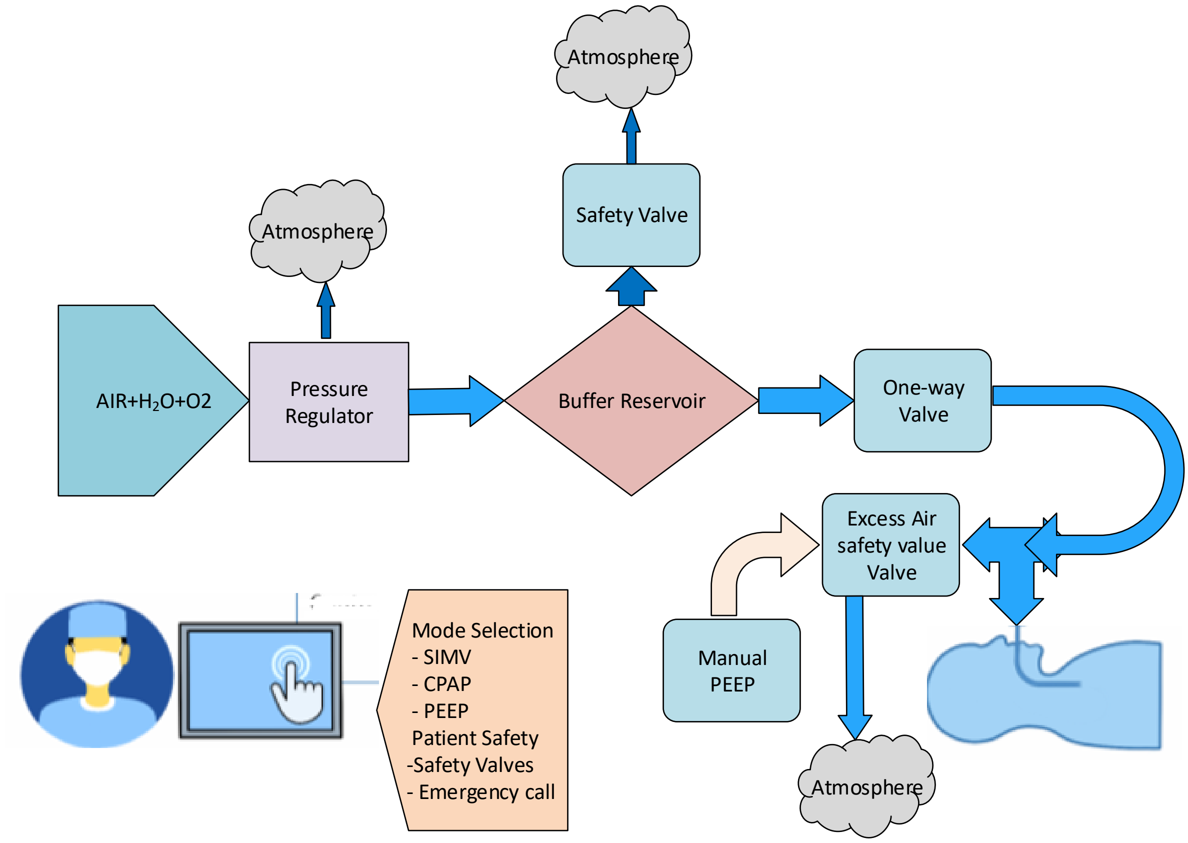

Figure 1: Proposed Ventilator Conceptual design

be between 2 and 5 bar. A push button feature is also provided for the patient that will help patient to call the doctor in case of any discomfort/emergency.

The connections presented by the unit to external input/outputs will follow hospital standards. The supply pressure is reduced by a pressure regulator to approximately 200 mbar. The system concept is based around a buffer volume (ambulatory bag) of approximately 1.6 litres. The filling of this buffer is controlled by the input valve (valve in). By controlling of the opening time, one can achieve the desired target pressure in the buffer after which the valve (valve in) is shut. This buffer filling occurs during the expiratory part of the breath cycle. If the buffer pressure is within tolerance of the required pressure, the output valve (valve out) is then opened, initiating the respiratory cycle. The respiratory rate, inspiratory time (corresponding to the open time of valve out) and pause time are all controllable. If a

PEEP pressure is set, then the pressure in the lungs will have the minimum of the PEEP pressure. In the case where the tidal volume is not achieved at a particular pressure setting, due to changes in the patient's airway resistance this can then be gradually adjusted. SIMV mode will allow the patient to take spontaneous breaths, and will assist the breathing when the spontaneous breath is taken. This mode uses an additional sensor for the detection of the negative pressure initiated by the patient breath. If the patient respiratory rate does not achieve the target value, additional mechanical ventilation is provided by the unit. During the operation all the parameters are measured and displayed using a suitable indicator panel (operator panel) which comprises an OLED display panel. The operator panel besides having necessary on off switches has emergency stop button as well, that bring the device into halt state for any procedures to be done by the doctor.

Specifications:

The proposed ventilator is designed with following specifications:

- Working Pressure: Up to 50 cm H2O.
- Operation modes: SIMV-PC, CPAP.
- Exhaust mode: PEEP available with a set range between 0 and 5 cm H2O.
- Minute volume flow capability: Up to 20 litres/min.
- Inspiratory flow capability: Up to 120 litres/min.
- Respiratory rate: 10–30 breaths/min.
- Inbuilt UPS functioning feature.
- Low battery feature for Inbuilt UPS
- Minimum calibrated air supplying capacity per stroke : 100 ml
- Maximum calibrated air supplying capacity per stroke : 650 ml

Methodology

The proposed ventilator essentially uses electronically controlled mechanical ventilation that is achieved by precise calculated periodic compression and expansion of a readily available ambulatory bag. The structural illustration of the ventilator are given below.

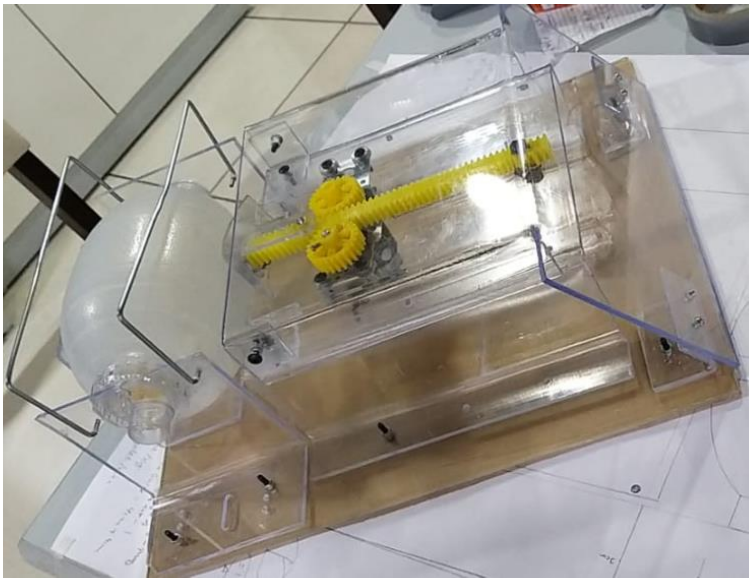

Figure 2: Mechanical illustration of proposed ventilator

Figure 2: Ventilator illustration showing excesses reservoir and oxygen input supply inlet.

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