Research Diary

Designing a low cost Ventilator during the COVID-19 crisis

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Introduction

Ventilators are some of the most critical medical devices needed by COVID-19 patients. Given the projections of numbers likely to be affected by the virus in India, and availability of ventilators in the country, a team was set up by the MAE department to develop a low-cost ventilator for emergency use in case supply of ventilators does not meet the demand. This ventilator with minimal specifications is termed as an 'emergency ventilator' in popular trending literature. The objective of this article is to give an elementary introduction on the design aspects of a ventilator, the challenges and the way forward.

Design requirements

From a simplistic point of view, the purpose of the ventilator is to provide a certain number of breaths every minute. During each breath, it has to supply a certain volume of air and monitor the pressure during the breathing cycle. However, the ventilators used in a typical ICU set-up in a hospital provide medical doctors with fine control and continuous monitoring of the respiratory function of a patient. In view of COVID-19 situation in the country and anticipating high demand for low-cost ventilators, GOI has recently provided specifications to be met by any ventilator that could be used in emergency care and are summarised briefly below.

One of the specifications mentions that the ventilator should be based on a turbine or compressor. The objective is that the ventilator can be used in hospitals/care centres which do not have a compressed air connection. Let us understand its implications. Let us say that an inhalation pressure of 30 cm of water was prescribed during an inspiration. Accounting for various losses, we can design a centrifugal air compressor to supply a pressure of 50 cm of water (this is equal to 5% of atmospheric pressure).

If the device has to be portable, it is preferable to have the compressor size to be less than 70 mm. Basic thermodynamics dictates that the impeller should have a speed of more than 20,000 rpm. Such compressors are usually made by specialized firms and not easily made in India, especially during the lockdown.

Another specification is that the ventilator should be capable of providing CPAP (continuous positive airway pressure) and PS (pressure support) modes. In the CPAP mode, the ventilator continuously supplies air to the airway such that the pressure is above atmospheric (typically about 5-20 cm of water). The objective is to prevent the alveoli from collapsing during exhale. A stand-alone CPAP machine is gaining its own importance due to which their portable versions are available even on e-commerce sites starting at INR 30,000. In the PS mode, the ventilator provides additional pressure during inhalation when compared to exhalation. In this mode, the ventilator detects when a patient is attempting to inhale (by monitoring the line pressure) and provides assistance so that the patient's effort is significantly reduced. The challenge here is that the ventilator should be able to rapidly adapt to the patient's breathing cycle.

Hence, the components such as pressure sensor, flow meter, compressor and flow control valve are required to have a fast response time (better than 0.1 s). This requirement may not be satisfied when we adopt a bag-valve-mask-based design of a ventilator.

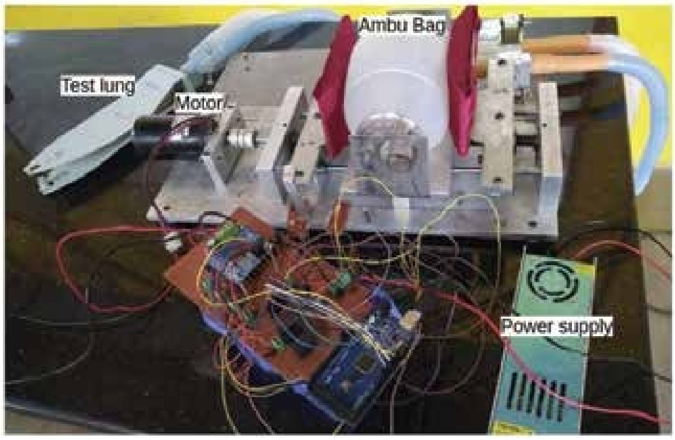

Figure 1. Ambu-bag based low-cost ventilator prototype Work at IITH

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Like many other institutions in the world, a small team began work on a ventilator design with a modest aim to cater to the need of emergency ventilators. Such emergency ventilators are based on periodically compressing an air sac called an AMBU bag, which is used by medical practitioners when a patient is being transferred to a regular ventilator. These are very low cost and simple devices that can be assembled with locally available components. Although the AMBU bag operator cannot precisely control either the pressure or volume flow to the lungs, it is possible to set and control these parameters to some extent using mechanical actuation of AMBU bags. With the addition of pressure and volume flow rate sensors and other flow control devices, the mechanical ventilator can be improved in performance.

We have explored several mechanisms of automating the AMBU bag for compressing, such as pneumatic, slider-crank, cam and lead-screw based (shown in figure 1). We found that pneumatic is in-fact best suited among all, however, due to lack of availability of compressed air we focused on lead-screw based design. We have developed one-side and two-side compression for single AMBU bag and one-side compression of double AMBU bag lead screw models. All three models are ranked with an increase in its performance. Further, the double AMBU bag gives flow close to that of a blower. We have fabricated these models at IITH central workshop and with the help of HMT and CITD -Hyderabad we are currently making industrial prototypes.

With the aim of developing a fully functional ICU ventilator, in addition to the AMBU bag-based ones, we are exploring a design based on compressor/turbine. Note that this is one of the specifications which a ventilator has to satisfy according to GoI. Since we are unable to procure a compressor that satisfies our requirements (50 cm of water at a flow rate of 40 lpm), we are developing an air compressor using the motor of a drone rotor and making an impeller in our central workshop. A prototype ventilator based on a blower design is shown in figure 2.

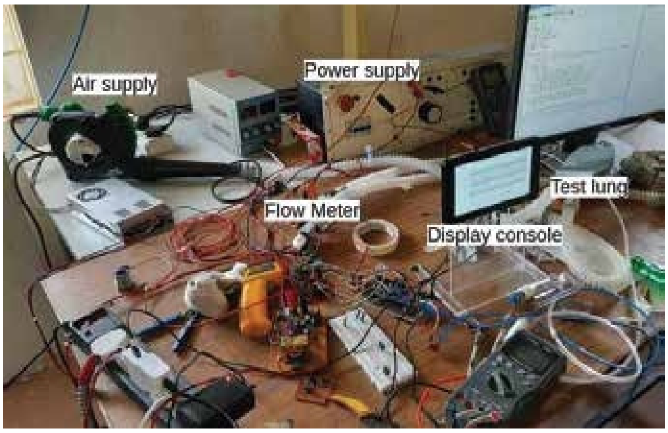

Figure 2. Blower-type low-cost ventilator prototype

Automation of the AMBU bag or the setting up of the right compressor is only one-third of the ventilator development. Ventilators also need a good flow circuit and fine electronic controls. Flow circuits consist of valves and sensors to control the flow as per the required specifications. Cost of the ventilator is dictated by the cost of sensors and valves. Most of them are imported, especially during lockdown it is difficult to find them. However, we have developed in-house flow sensors to calibrate the flow, which will be discussed later in detail. One of the crucial components of a ventilator is a volume flow meter which can precisely measure the quantity of air being delivered to the lung. Due to non-availability of flow meters during the ongoing crisis, a new low-cost volume flow meter was developed for the ventilator project. A variety of designs were pursued ranging from an ultrasonic flow meter which uses time differences between sound pulses travelling in the medium to determine flow rate to a hot wire anemometer which uses changes to the resistivity of a wire when air flows over it. After many attempts, a paddle flow meter shown in figure 3 was developed. This sensor has a tiny blade connected to a needle

IR sensors are used to calculate the rotation rate and the flow meter was calibrated using a commercial spirometer.

Figure 3: Paddle flow sensor connected to the Ventilator

The final part of the ventilator is the input-output console, we have used Arduino-Mega and python scripting to develop user-friendly interface and ventilator control. Efforts are currently underway to refine current designs in order to meet GoI norms.

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