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Smart ventilator splitter

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Contents

1 General context

Due to the actual pandemic situation the world is facing, hospitals are stuggling to provide care to all the people that are in respiratory distress. Indeed, because of the lack of mechanical ventilation devices, many hospitals made the choice to split the ventilators to allow more patient to be treated.

However, this solution has many drawbacks. This implies that the ventilator is set to pressure-controlled mode, which is the only way to have controlled on the delivered pressure. This also implies that all the patient linked to the same respirator have the same needs in pressure and oxygen and also the same contagious disease.

To adapt to this new pandemic, multiple DIY ventilators have been elaborated and are available in open source format [4]. However, those solutions are not widely used by hospitals as they need to undergo tests that take time the world doesnot have dealing in this time of emergency [6].

Another solution would be the creating of a "smart splitter". This device would be used with already existing ventilators to split the airways. The main advantage it would have would be the capability of monitoring both the delivered pressure and the positive end expiratory pressure for both patient. This would enable hospital to link to patient that donot necessary have the same needs in pressure to the same ventilator.

2 Technical parameters

Ventilators modes

The ventilators can be controlled in volume (AC mode) or in pressure (PC mode).

Our project would be focused on the fully support mode for patients that have the same respiratory rate, which is common and around 15 breaths per minute and the same O2 concentration. Our device would allow the physician to regulate the pressure for each patient and the volume needed for each one of them. Here, we can see a typical patient setting :

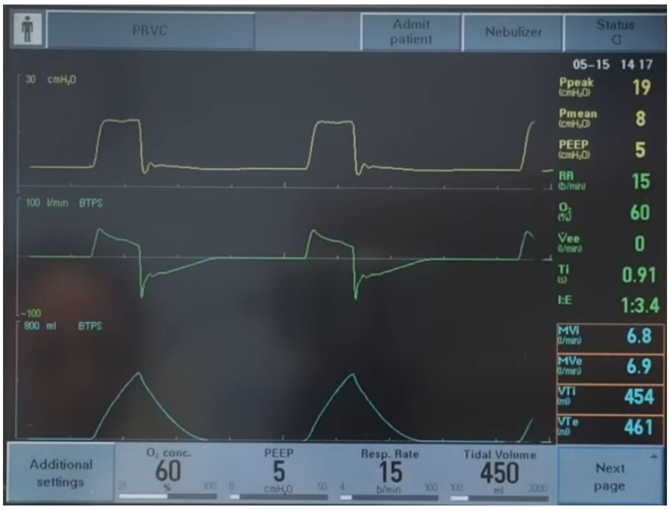

Figure 1: Typicla setings of a respirator. ref : Albert Einstein College of Medicine

So the physician would have to set the cumulative tidal volume of the two patients, the lowest PEEP (constant pressure after the exhale) parameter and the highest peak pressure of the two patient. The O2 conentration would be the same for the two patients. The physician would also have to set on our device the individual tidal volume, the PEEP value and the peak pressure. This way, our device with its flow and differencial sensor would be able o conrol the valves via a feedback loop.

Parameters

The physician can set parameters that regulate each patients' respiratory cycles. These parameters are presented below:

- Tidal volume [TV]: it is the volume injected on the patient lungs at each inspiration. TV is set under the AC mode.
- Fraction of inspired oxygen [FiO2]: it is the volumetric fraction of oxygen in the inhaled air the patient is receiving.
- Positive expiratory end pressure [PEEP]: it is the pressure remaining in the lungs after expiration. This constant positive air pressure exerted in the airways prevents the alveoli to collapse at the end of each breath.
- Backup rate: it is used in modes in which the patient triggers the respiration. It ensures that a minimal frequency of breath if performed. If the patient does not trigger after $T > T_{min}$, then the ventilator initiate the breath automatically.

3 Design proposition

The idea is to design a splitter on which parameters such as the delivered pressure and the PEEP can be monitored.

Assumptions and requirements

To achieve this design whithin the time dedicated to the hackathon, some assumptions had to be made.

- The adequate delivered pressure is set on the ventilator which is used under PC mode.
- The PEEP and the delivered pressure that suit each patient can be set directly on the smart splitter.
- The ventilator initiates each breath: there are no backup rates.
- The FiO2 value cannot be monitored for each patient: it must be set on the ventilator and the oxygen needs must be the same for both patients.
- Both patient must either have the same contagious disease (eg: COVID) or no contagious disease at all.

Concept

The concept developed during the hackathon is presented on Figure 2. It consists of a Y-shaped device on which the flow delivered by the ventilator (of a fixed pressure P_0 and flow rate F_0) is devided. Downstream the junction, on each airways, the flow is controlled by an automated valve ($Valve_1$ and $Valve_2$). The opening of the valve is set by the wanted pressure of the flow on the patients' side which is set on the splitter (P_1 and P_2).

To monitor the pressure and the flow on both airways, a differential pressure measurement is establish with pressure sensors downstream and upstrem the valve (dP_1 and dP_2). Moreover, flow sensors are placed at the end of both airways (F_1 and F_2).

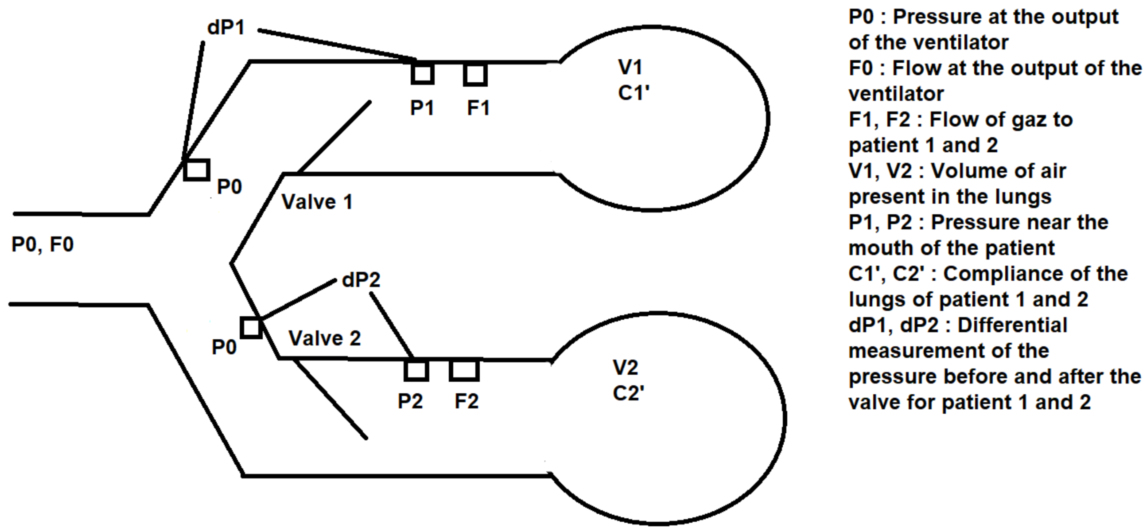

Figure 2: Model splitter

Materials

Regarding the materials, the idea was to do the Y-splitter in a biocompatible polymer. Those materials have the advantages of being light weight, biocompatible and quite robust and many of them have been approved by the US FDA (Food and Drugs Administration).

According to existing breathing circuit sets for mechanical ventilators, connectors sur as T-pieces or Y-pieces are made of thermoplastics such as polycarbonates [PC] or polypropylene [PP] [1]. The difference between both material resides in the nature of their monomers and the process of polymerization. However, PC seems to be a better option for its use of machinability.

Regarding the valves of both airways, the choice of material is wider as both metals and polymers are eligible. For their higher robustness, metals such as stainless steel, titanium and its alloys (nitinol), chromium and cobalt can be chosen. As their robustness are approximately equivalent, the choice has to be made with their respective corrosion resistance.

As seen on endobronchial valves, nitinol as well as are silicone are used for airways [2]. As a rigid material is needed for this valve concept, nitinol would be the material of choice. Nitinol presents many advantages such as high mechanical performances, high corrosion resistance, compactness and lightness [3]. Moreover, the fact that nitinol is also widely used in other medical equipment and devices* confirms this choice.

Dimensions

The plastic tubing has a 22mm inside diameter. The connectors also have universale dimanesions of 22mm outside diameter and 15mm inner diameter.
The Y-shaped "smart splitter" device have the same dimensions as those connectors.

4 Monitoring system

A pressure and PEEP monitoring system has been elaborated during the hackathon (see Figure 3). The sensors added to the model measure the pressures and flows shown is Figure 2. The controller function shall then input these parameters and output the two pneumatic regulators control signals. However, this needs to be deepened during the semester project.

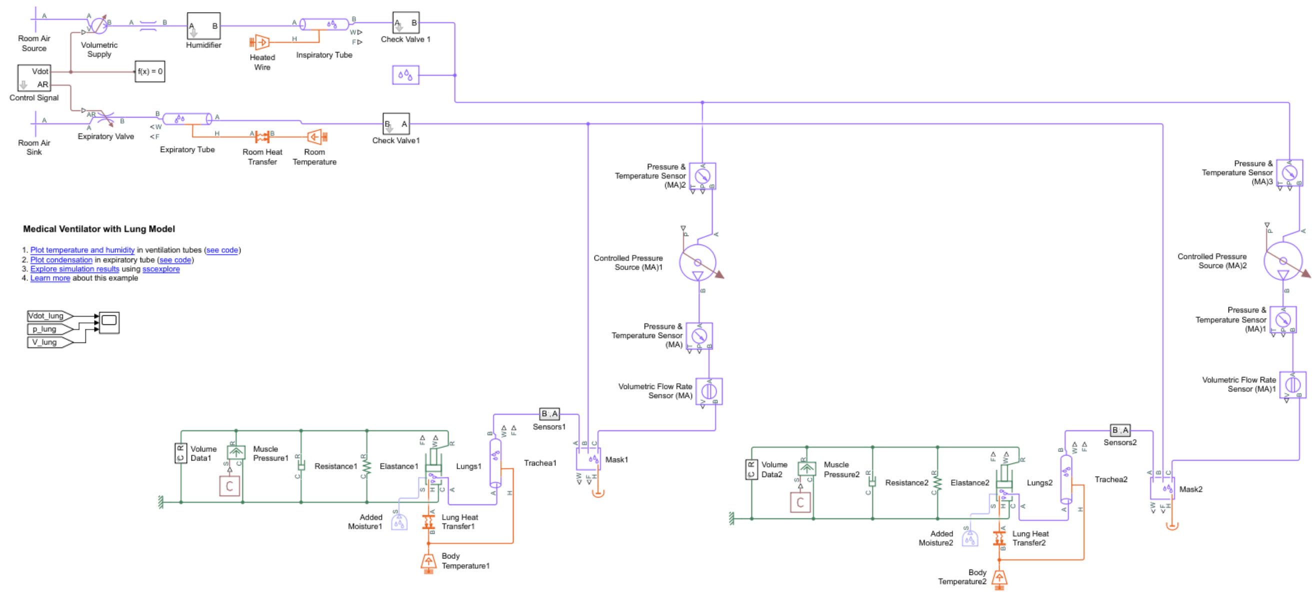

Figure 3: Monitoring system of the device, model based on the one found under: https://ch.mathworks.com/help/physmod/simscape/examples/medical-ventilator-with-lung-model.html

5 Future work

To enhance the present model, multiple studies have to be made. This work can be performed as part of a semester project.

Two major implementations have to be made:

- Monitoring system
- Implement appropriate pressure regulators

On top of that, many optimization of the device can be made.

CFD simulations

The computational fluid dynamic [CFD] simulations would enable to analyse the air flow behavior in the device.

The shape of the valve can be optimized with CFD studies. Indeed, multiple valves can be tested and, with those studies, the optimal valve design can be established considering the possible recirculation of the air flow.

Morover, it can be established if the angle between the two airways has an influence on the air flow behavior. If so, an optimization of this angle can be performed.

Other implementations

As said on the first section (Assumptions and requirements), the needs in oxygen concentration [FiO2] must be the same for the both patients. In order to monitor this parameter to fit each patient, the splitter must ideally present a monitoring system for oxygen.

Risk analysis

A risk analysis can be performed to provide solutions to possible complications and their consequences.

- Alarm system coupled to pressure and flow sensors on each airways
- Cross contamination risk

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