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Design the motor acceleration for the desired frequency air volume inspiration of asynchronous mechanical ventilator based on a pressure sensor

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Abstract. The SARS-CoV-2,a virus that attacks the respiratory system, has some difficulty breathing and chest pain. A mechanical ventilator is a simple version of a ventilator and most used to support patient breathing because it iseasy to use.This research design a mechanical ventilator operate based on the frequency and air volume of inspiration.The operator can set the ventilator using a potentiometer and choose the menu on an LCD. A couple of press wall push a bag valve mask in the desired frequency. The motor speed has a vital role to perform the number pushing based on the desired setting. The amount of airflow out from this bag depends on the duration and the depth of pushing. Some standard frequencies of human breathing were investigated in the range of 12 to 20 times of inspiration in a minute. The acceleration of the ventilator based on calculation was implemented to the machine, and it reduced the number frequency to 64% of the desired frequency. An error compensator is used to improve the accuracy of the ventilator. It compensates by multiply calculated acceleration by 2.31. It is successfulin improving the performance and resulted in the ventilator work in the desired frequency and volume.

1. Introduction

The number of novel coronavirus cases is increasing since December 2019, firstly identified in Wuhan, China[1]. The saliva droplet from the infected person is easy to spread to other people and infect the community. WHO reported that there are 1.3 million death cases from 50 million patients in 220 countries only in 11 months.This virus damage level varies from just a simple cold to severe respiratory problems such as pneumonia. In any case, infected people have no symptoms [2].

Neither proven treatment nor vaccine applicable to solve the problem caused by this virus. But in common, the patients with a bad condition need medical assistance for respiratory since the virus harms the lungs caused breathing obstacles. Ventilator plays a vital role in these situations. It helps patients to keep breathing in a critical condition[3].

A mechanical ventilator is one of the many interventions for the patient with lung damage. This ventilator can maintain the amount of oxygen supplied to the patient in the Intensive Care Unit (ICU)[2]. This pandemic raises the need for this machine. The advanced production of the existing ventilator or the new one is being pushed to fulfill the gap[3].

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The ventilator has three modes pressure, volume, or hybrids[4]. Many researchers and the community tried to develop a safe and low-cost mechanical ventilator to fulfill the pandemic's mechanical ventilator requirement[5]. The non-invasive ventilators are more likely to be developed quickly according to patient needs. Some standard variables used in a ventilator to examine patients are airflow, air pressure [6–8], cycle variable,and the inspiratory phase of breath[9].

In this research, an asynchronous non-invasive mechanical ventilator was designed. This article reports primarily findinghow to set control the motor to get the desired number of inspiration. This control important to get the expected time, volume, and pressure.

2. Materials and methods

This research designed a motor acceleration considering the inspiration rate and air volume gave to patients. This is a portable ventilator with a graphic menu for the operator. A bag valve mask is compressed from two sides. A pressure sensor measures the inspiration airflow.

2.1. Electrical Component

A ventilator is designed to work in the desired frequency and volume of inhalation. The components used for this ventilator are shown in figure 1. An LCD shows the menu for the operator. The operator can rotate the potentiometer to set the frequencyand volume of inspiration. Two motors with the driver move the wall to press the bag valve mask (BVM). A differential pressure sensor measures air flowing through the BVM's neck. As the center of the device, a microcontroller receives the potentiometer input and givessignal to the LCD and the two motors as output. This ventilator requires a 24 V power supply and one voltage regulator, 24 V to 5 V. Figure 1 shows the designed ventilator scheme.

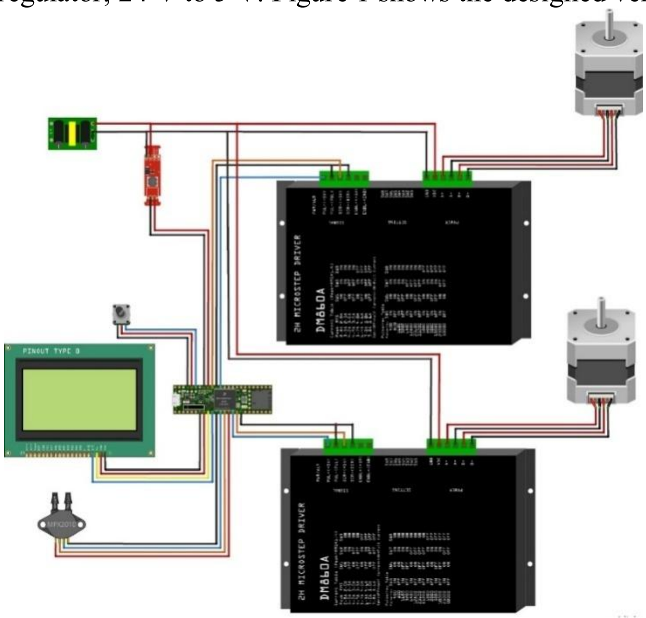

Figure 1. Scheme for ventilator.

2.2. Ventilator Box

The designed ventilator has a box packaging. Figure 2(a) is the front view,and figure 2(b) is the top view of the ventilator. The operator rotates the potentiometer (1) and choosessome menu on LCD (2).A differential pressure sensor measures the gap air pressure inside respirator tube 3(a) and outside 3(b).A microprocessor (4) is inside the box. This microprocessorreceives an input signal from the sensor and potentiometer. This device processes the signal and generatesa command fortwo motor drivers. These drivers operate the left motor (5a) and right motor (5b). Both motors shift the left wall (6a) and right (6b). The shifting of the wall press will push the BVM (7). Air flows to the patient through the tube (9) when the BVM is pushed.

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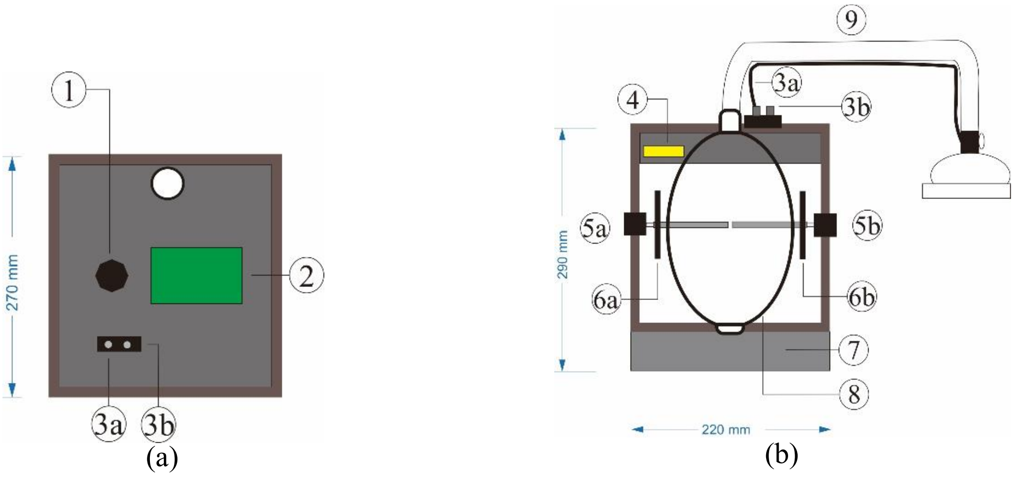

Figure 2. (a) Front view and (b) top view.

2.3. Air Volume

Air will flow to the patient from BVM if air pressure is generated [10]. This pressure is generated if the wall press pushes the BVM. It flows through the tube to the patient. This flow is irreversible because of the BVM design. It just only can go in one direction. The illustration is shown in figure 3.

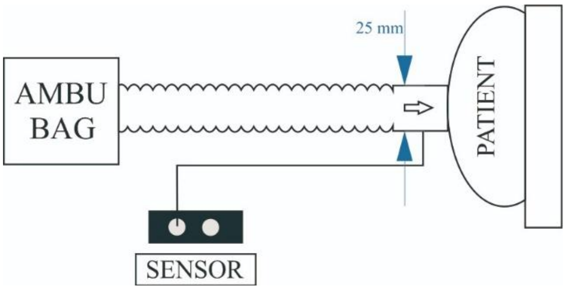

Figure 3. Airflow from Ambu-bag to patient.

A differential pressure sensor[11]measures the gauge pressure inside the tube. The air velocity inside the tube is calculated based on the assumption that the atmosphere's air velocity is equal to zero. Based on the Bernoulli equation, the air velocity inside the tube is determined using equation (1).

$$v = \sqrt{\frac{2\Delta P}{\rho}} \tag{1}$$

Where

v = air velocity (m/s),

ΔP = air pressure (Pa)

ρ = mass density (kg/m^3)

The flow rate of air transfer to the patient for each push is calculated by (2).

$$Q = v.A \tag{2}$$

Where

Q = flow rate (m^3/s)

v = air velocity (m/s),

A = area inside the tube (m^2)

The volume of airflow to the tube is equal to (3).

$$V = Q.t \tag{3}$$

Where

V = volume (m^3)

Q = flow rate (m^3/s)

t = time (s),

2.4. Motor acceleration

The inspiration rate affects the frequency of pushing BVM. Figure 4 illustrates the ventilator while pushing the BVM.The two press walls push the BVM with distance (d) from the left and right sides. The walls move from the normal position to the center. After pushing the BVM at the desired distance, the two walls areback to the normal position until the BVM is released. The total distance pass by a wall press is twice of d, as shown in equation (4).

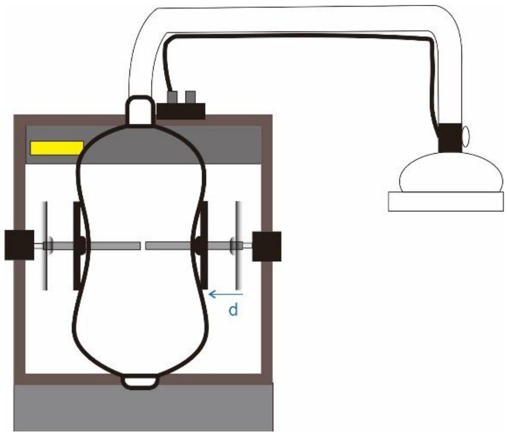

Figure 4. Airflow from Ambu-bag to patient.

$$d_{total} = 2.d \tag{4}$$

Where

d = the desired pushing distance (cm)

d_{total} = the total length passed by a suppressor after back to the normal position (cm)

One cycle for inspiration and expiration is when the initial position wall pushes the BVM to the desired distance and back to the normal position. The time for one process is called a period. The number of inspirations in a minute is the inspiration rate. It is equal to equation (5).

$$f = \frac{60}{T} \tag{5}$$

Where

f = inspiration rate (inspiration/minute)

T = Period of one cycle (second)

The period of one cycle affects the acceleration motor to push BVM. The movement of the press wall indicates motor acceleration. The acceleration of the press wall to pass the desired distance is (6).

$$a = \frac{2d_{total}}{T^2} \quad (6)$$

Where

a = motor acceleration (cm/s^2)

d_{total} = the total distance passed by a suppressor after back to the normal position (cm)

T = Period of one cycle (second)

3. Results and Discussion

An experiment to determine the acceleration of the press wall to receive the desired inspiration rate was performed. The total distance (d_{total}) was set constant at 4 cm, and the desired frequencies were varied from 12 to 18 inspirations in a minute. The inspiration rates were varied to know the error of frequency. The result shows in table 1.

Table 1. Formatting sections, subsections and subsubsections.

f_d	f_a	f_e	T_d	T_a	T_e	a_d	a_a	a_e
12	7	5	5.00	7.50	2.50	0.32	0.14	0.18
13	8	5	4.62	6.59	1.97	0.38	0.18	0.19
14	10	4	4.29	6.06	1.77	0.44	0.22	0.22
15	10	5	4.00	5.70	1.70	0.50	0.25	0.25
16	10	6	3.75	5.34	1.59	0.57	0.28	0.29
17	11	6	3.53	5.44	1.91	0.64	0.27	0.37
18	11	7	3.33	5.25	1.91	0.72	0.29	0.43

The ventilator that was designed before being implemented the error compensator turned out not to work as desired. There is a difference in the amount of inspiration rate generated by the ventilator, and the desired frequencyis r_f. The average system only reaches 64% of the desired frequency, with 153%of the desired time. This means the system is running slower than expected. Based on the calculation, the acceleration obtained was only 43% of the set point. The ratio between actual acceleration and desired acceleration is r_a. Therefore, it is necessary to compensate for the error with 2.31 of the desired acceleration. This is the final acceleration value of the press wall after getting compensation. The complete ratio between actual to the desired frequency, time cycling, and acceleration is shown in table 2.

Table 2. The ratio of actual to the desired variable.

f_d	r_f	r_t	r_a
12	0.58	1.71	0.34
13	0.62	1.61	0.39
14	0.71	1.41	0.50
15	0.67	1.43	0.49

16	0.63	1.42	0.49
17	0.65	1.54	0.42
18	0.61	1.57	0.40

Experiments to determine the amount of air pumped by the ventilator in each inspiration are carried out by varying distances. The resulting volume increases from the smallest to the largest distance. It is proof the Bernoulli's equation work in this ventilator. The system works more stable, the further the pressing distance. The need for human inspiration, which is 5 to 10 L for each inspiration, can be fulfilled with encouragement from this wall press, especially at a distance of 4 cm. Table 3 shows the volume of air transfer to the patient from BVM at various lengths.

Table 3. The volume of air from BVM.

d	$\bar{V}$ (L)	SD
2.5	2.49	0.86
3.0	2.96	0.31
3.5	4.16	0.70
4.0	5.51	0.16

4. Conclusion

An asynchronous mechanical ventilator is designed in this research. This article mainly focuses on the acceleration performance to get the desired inspiration rate. An error compensator for the acceleration is implemented to the system 2.31 of the desired acceleration. This compensator fulfilled the required frequency of inspiration. The ventilator also produces enough air volume for the patient.For future development, the measurementof the expiration air volume and pressure are urgently required. The implementation of an early warning system if a system works improperly is also essential.

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