CERTIFICATE
OF PRESENTER

No.: 9/FTI-UBH-ESTIC5-P/IX/2020

This certificate awarded to

Hidayat

Universitas Bung Hatta

as The Presenter in

The 5th Engineering Science and Technology International Conference (ESTIC) 2020

With theme **"Applied Technology for Sustainable Development"**

Held virtually on Wednesday, September 9, 2020

by title

Design and Implementation of Ventilator for Breathing Apparatus

Organized by
Faculty of Industrial Technology
Universitas Bung Hatta
https://...ac.id

Chairman of the Committee

the 5th ESTIC 2020

Dr. Burmawi, S.T., M.Si.

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Volume 990

2020

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The 5th Engineering Science & Technology International Conference 5-6 August 2020, Padang, West Sumatera, Indonesia

Accepted papers received: 10 November 2020

Published online: 01 December 2020

Open all abstracts

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Design and Implementation of Ventilator for Breathing Apparatus

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IOP Conference Series: Materials Science and Engineering, Volume 990, The 5th Engineering Science & Technology International Conference 5-6 August 2020, Padang, West Sumatera, Indonesia

Citation Hidayat *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **990** 012007

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https://doi.org/10.1088/1757-899X/990/1/012007

Abstract

This paper present the design and implementation of a ventilator for a breathing apparatus. The ventilators that developed are the positive pressure ventilation type, the cycled volume mode and the controlled mechanical ventilation method (CMV). The technology that used is the ambu bag. The design and manufacture includes an automatic ambu bag pressing mechanical system and a control system using the arduino microcontroller. The mechanical design that is compact, lightweight, energy saving, low cost, meets aesthetics and is friendly makes this tool attractive so it is not scary for patients. BPM (beep per minute), IER (inspiratory expiratory ratio) and TV (tidal volume) parameters can be controlled via a touch screen or remotely using a mobile phone via 4 buttons

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Design and Implementation of Ventilator for Breathing Apparatus

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Abstract. This paper present the design and implementation of a ventilator for a breathing apparatus. The ventilators that developed are the positive pressure ventilation type, the cycled volume mode and the controlled mechanical ventilation method (CMV). The technology that used is the ambu bag. The design and manufacture includes an automatic ambu bag pressing mechanical system and a control system using the arduino microcontroller. The mechanical design that is compact, lightweight, energy saving, low cost, meets aesthetics and is friendly makes this tool attractive so it is not scary for patients. BPM (beep per minute), IER (inspiratory expiratory ratio) and TV (tidal volume) parameters can be controlled via a touch screen or remotely using a mobile phone via 4 buttons remotely to facilitate and avoid transmission of Covid-19 to medical personnel. BPM can be set from 5-20 BPM, IER from 1: 1 to 1: 4 and TV from 40-100%. The results of ventilator testing that have been done show a good response.

1. Introduction

Ventilator as a breathing apparatus has recently become a hot topic at the national and international. The issue is the lack of availability of a ventilator to treat Covid-19 patients. Most of the deaths of corona patients in Japan can be caused by a lack of ventilators [1]. The number of Japanese-made ventilators is very lacking in Japan, so the Japanese government urges ventilator manufacturers to increase production and facilitate registration [2]. The number of positive patients infected with corona in Indonesia is more than 8,057 people and in the world 2.73 million people [3]. The main complaint of Covid-19 patients is generally respiratory problems ranging from mild to severe disorders due to lung infections which can lead to death [4]. In several cases, the corona virus can cause damage to the lungs, so that the body's oxygen levels drop and make breathing difficult. In medical science, patients who have difficulty breathing, breathing is assisted by a ventilator. A ventilator is a medical device used to help patients who have difficulty breathing or are unable to breathe on their own. The ventilator will take over the patient's breathing. Not different from other countries, one of the problems in handling corona patients in Indonesia is the limited number of ventilators available in hospitals. Besides the high price, the stock to be purchased is also not available. This is what has prompted several foreign and domestic institutions and universities to design practical, economical and ready-to-

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use ventilators. ITB with its Vent-I, ITS with Robot Ventilator, UI, UGM, UNS, BPPT, ESDM Research and Development and so on. Likewise with overseas universities such as MIT in the United States, Oxford University, Rice University, etc. Including multinational industries such as the automotive industry, PT. Pindad, PT. LEN and so on. Because of the urgency of ventilators these days, these works are published openly (open source) and researchers are allowed to develop them without the need for permission. One of them, recently Dr. Saud Anwar in America succeeded in making a Ventilator that can serve 7 patients at once. Dr. Saud Anwar gave a correspondent address for those interested in making the ventilator he found

2. The Theory of Ventilator

Mechanical ventilation is an attempt to assist breathing with a mechanical breath aid. Ventilator as a means of replacing the chest pump function that is experiencing fatigue or failure. Mechanical ventilation is used to assist or replace spontaneous breathing. Mechanical ventilation is applied with a special tool that can support the function of ventilation and improve oxygenation through the use of gases with high oxygen content and positive pressure. In its current development, mechanical breathing aids are not only a substitute for the function of the chest pump, but more broadly, namely overcoming pulmonary ventilation-perfusion disorders, so that this breathing device is agreed as a life-saving tool for critical patients who need intensive therapy. The main objectives of mechanical ventilation allowance are to ensure adequate ventilation, reduce breath work, and correct impaired oxygen exchange in the alveoli. The function of the ventilator, expanding the lungs during inspiration, can regulate the time from inspiration to expiration, prevent the lung from contracting during expiration, and can adjust the time from the expiration phase to the phase of inspiration. All sophisticated mechanical ventilators are equipped with a pressure gauge monitor, a pressure limiter to prevent the lungs from barotrauma (pressure limiting device), high and low pressure alarms, and pulmonary volume regulator (spirometer).

2. 1. Classification of the ventilator

The classification of ventilator such as negative pressure tank respiratory support (NPTRS) and positive pressure ventilation (PPV). NPTRS is the patient is placed in a cylinder that is pressurized by sub-atmospheric air (negative pressure), causing the chest to expand and the airway pressure to be negative. PPV will provide positive pressure above atmospheric pressure so that the chest and lungs expand in the inspiratory phase, then at the end of inspiration the pressure returns to equal atmospheric pressure so that air exits passively in the expiration phase. During positive pressure ventilation, pulmonary inflation is achieved by periodically applying positive pressure to the upper airway through a tight mask (non-invasive mechanical ventilation) or through an endotracheal tube or tracheostomy.

2. 2. Ventilator Model

Ventilator mode is divided based on cycling (change from inspiration to expiration) such as:

a) Pressure Limited / Pressure cycled

The pressure-cycle ventilator goes into the expiratory phase when the air pressure reaches a predetermined level. Tidal Volume (TV) and inspiratory time varied, with respect to airway and pulmonary resistance and circuit compliance. In its application, this tool is easier to accelerate by the patient's breathing effort, but when the airway resistance increases or the chest or lung stretching power increases, there will be a decrease in tidal volume and minute volume.

b) The time-cycled

Time -Cycled ventilator enters the expiratory phase after a predetermined interval calculated from the start of inspiration. TV is a product of the time of inspiration and the flow rate of inspiration. Time-cycled ventilators are commonly used for neonates and in the operating room.

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c) Cycled volume

This type of ventilator can produce a certain volume that is tailored to the patient's needs. When the set volume is reached, the inspiration phase ends. Many ventilators for adult patients are volume-cycled but equipped with a secondary limit on inspiratory pressure to protect the lung from baro trauma. If the inspired pressure exceeds the pressure limit, the engine cycle continues on to expiration even if the selected volume has not been conveyed.

d) Flow cycled

The inspiratory phase changes to expiration when the air flow falls to a certain level. Flow-cycle ventilators have pressure and flow sensors that allow the ventilator to monitor inspiratory flow at a preset inspired pressure; when this flow reaches a predetermined level.

3. Design and Implementation

3. 1. Description

The ventilators developed are the Positive Pressure Ventilation type, the cycled volume mode and the Controlled Mechanical Ventilation method (CMV). The technology used is the ambu bag. The design and manufacture includes an automatic Ambu Bag pressing mechanical system and a control system using the Arduino Microcontroller. A mechanical design that is compact, lightweight, meets aesthetics and is friendly makes this tool attractive so it is not scary for patients. BPM, IER and TV parameters can be controlled via a touch screen or remotely using a cell phone via 4 buttons remotely to facilitate and avoid transmission of Covid-19 to medical personnel. BPM can be set from 5-20 BPM, IER from 1: 1 to 1: 4 and TV from 40-100%. The ambu-bag technology was chosen because it is cheaper and can be produced in mass quantities.

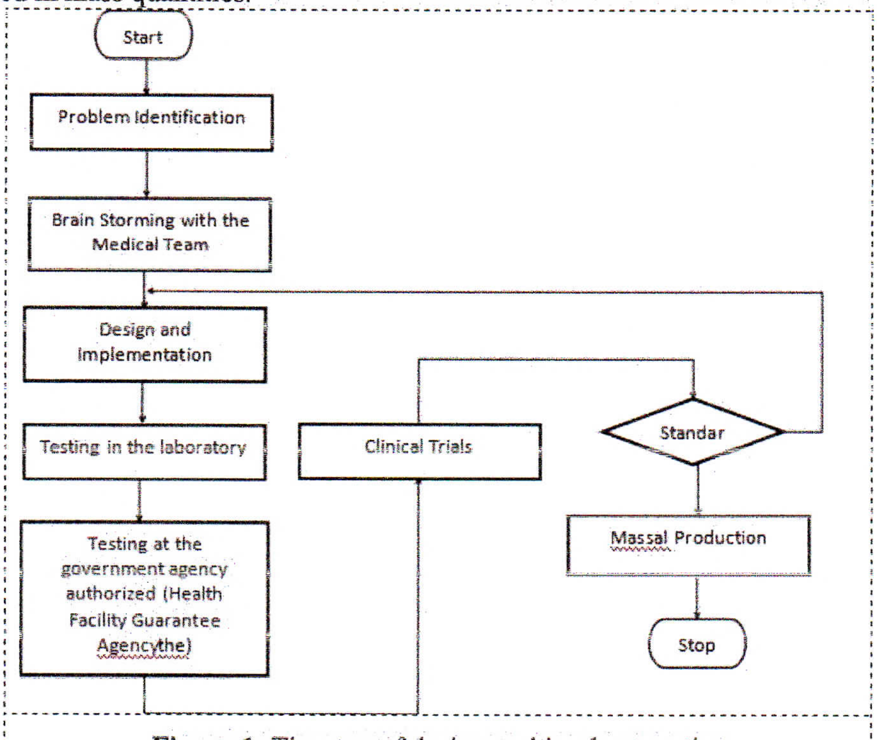

Figure 1. The step of design and implementation

The power capacity determination for the arm drive component is calculated so that it consumes minimal electrical energy. The arm shape and position of the Ambu Bag press are designed to follow the surface of the Ambu Bag, resulting in maximum tidal volume. To stabilize the position of the Ambu Bag when it is pressed, which tends to shorten, a motor that controls the position of the Ambu

Bag is installed which moves in sync with the Ambu Bag suppressor motor. The step of design and implementation is shown Fig. 1. Design specifications of ventilator such as: using the ambu bag, respiratory rate (RR) = 5-20 breaths per minute (BPM), inspiratory: expiratory time ratio (I: E ratio) = 1: 1 to 1: 4, tidal volume (TV) = volume of gas (ml) delivered during inspiration: 250-800, setting with touch screen and hand phone

3. 2. Determination of Motor Power

The mechanical system for pressing the Ambu Bag is planned to have a gripper with two motors, each of which is separated during the pressing and releasing process. So that the calculation of the power of each motor refers to the specifications of the ventilator as follows [3]. Maximum pressure on the airway (airway): P airway, max = 40 cm H_2O; Maximum respiration rate: RR max = 20 bpm; The minimum inhale / exhale ratio is 1: 4: IE ratio, min = 4; Maximum output volume: V max = 800 cm3 In the worst case, the air flow is generated at a pressure of 40 cm H2O, in 0.3 seconds.; = 60 sec / RR max: time in 1 bpm; tin hale = pressing time; tin hale = T/(1 + IE ratio); tin hale = 60 sec /RR max / (1 + IE ratio); Volumetric flow rate required in the worst conditions (peak); Q airway = V max / tin hale = 0.0027 m3 / s; The output energy (in the form of a pressurized volume flow in the airways) is: Power airway = Pair way, max Q air way = 10.46 W. However, some of the power used to compress the Ambu Bag is lost (ambu bag deformation, friction, etc.), and an estimated 50% is converted to a pressurized volume flow. Taking into account efficiency, the power required by the gripper is: Power gripper = 2 Power airway = 20.92 W. Assuming half of the motor power output is lost to mechanical and electrical inefficiencies (gears, thermal dissipation, etc.), the required power output of the motor is given by: Power motor = 2 Power gripper = 41.84 W. The ventilator is designed to use a gripper with 2 fingers. Parameters that can be obtained by measurement such as ambu bag contact area, the length of the lever arm, sweep angle. For typical prototypes, note that: Maximum Ambu Bag contact area: Abag = 90 mm x 115mm Length of the lever arm: finger = 12 cm ; Sweep angle: α_{sweep} = 30°; The maximum strength of the one finger Ambu Bag (when fully pressed) is, using the same 50% pressure transmission efficiency as before: F_{finger} = 2 A bag Pair way, max = 81,199 N. The maximum torque required for each finger is: finger = F_{finger} l_{finger} = 9.74 N.m. The power required for a two-finger gripper using the sweep angle rate (in 0.3 seconds): $P_{gripper}$ = 2 x finger w_{finger} = 34.01 W. The total power for the motor (assuming a single motor) with an additional 50% and the same gearbox efficiency, is obtained: P_{motor} = 2 x $P_{gripper}$ = 68.03 W ~ 70 W.

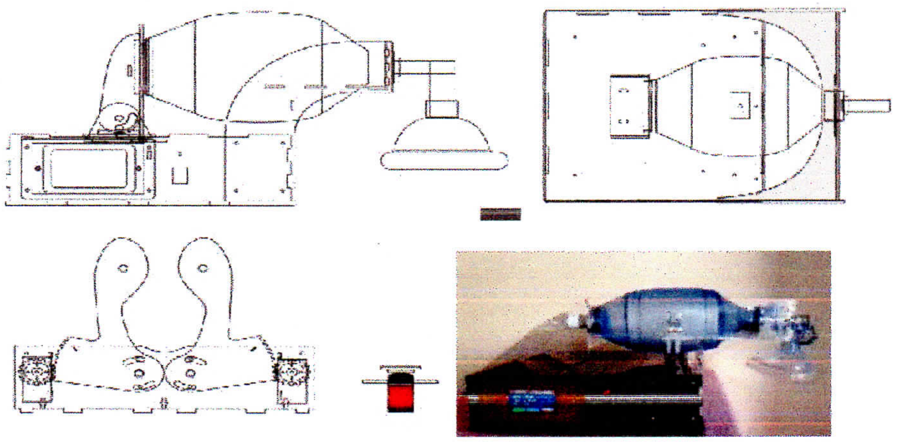

Figure 2. Ventilator Engineering Drawing.

4. Test Result and Analysis.

The test was carried out using the following equipment, that are computer, stopwatch, vessel and measuring cup. The step of testing technical are given the RR, IER and TV values, noted the time pressing (Inspiratory, Ti) releases (Expiratory, Te) the ambu bag, noted the BPM value, measured the volume based on the amount of water spilled and calculated the IER value. The first test is given setting value of BPM = 15, IER = 1: 1 and TV = 80%, then the ventilator is activated. The results obtained are BPM = 15, IER = 1: 1 and TV = 80%. This shows that the ventilator can respond according to the amount given by the ventilator. Then second test is given, namely the setting BPM = 15, IER = 1: 2 and TV = 80%, then the ventilator is activated. The results obtained are BPM = 15, IER = 1: 2 and TV = 80%. This shows that the ventilator can respond according to a given amount. By the test results, it can be seen that the ventilator is able to respond to the given setting values quickly. The test results for the other parameters can be seen in Table 1. Changes to test parameters can also be done remotely via hand pone.

Table 1. The test result of ventilator

No	Setting value			Actual Value				
	BPM	IER	TV (%)	BPM	Ti (dt)	Te(dt)	IER	TV(%)
1	15	1:1	80%	15	2	2	1:1	80%
2	15	1:2	80%	15	1,30	2,60	1:2	80%
3	12	1:2	80%	12	1,60	3,30	1:2	80%
4	10	1:2	80%	12	2	4	1:2	80%
5	15	1:1	60%	15	2	2	1:1	60%
6	15	1:2	60%	15	1,30	2,60	1:2	60%
7	12	1:2	70%	12	1,60	3,30	1:2	70%
8	10	1:2	70%	12	2	4	1:2	70%

5. Conclusion

The ventilator is designed to be very friendly in terms of performance and physical appearance is not scary Changes to test parameters can also be done remotely via hand pone. Every change in the parameters given, the ventilator can respond and work as desired. Ventilator testing will continue to the testing phase at the Medan Health Facilitation Guarantee Agency, which is an institution that provides guarantees for medical equipment, namely BPFK Medan

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