[1.]Mustefa JIBRIL, [2.]Mesay TADESSE, [3.]Nurye HASSEN

MECHANICAL VENTILATOR DESIGN FOR COVID-19 PATIENT WITH RESISTIVE BELT SENSOR

[1-3.]School of Electrical & Computer Engineering, Dire Dawa Institute of Technology, Dire Dawa, ETHIOPIA

Abstract: A ventilator is a machine that gives mechanical ventilation by moving breathable air into and out of the lungs, to convey breaths to a patient who is genuinely unfit to inhale, or breathing deficiently. In this paper, a resistive chest belt sensor based mechanical air ventilator is designed to give the COVID-19 patient the desired air volume to inhale based on the expansion of the patient chest for needing more air. The resistive belt sensor senses the expansion of the patient chest and controls a solenoid valve that attached with oxygen compressor. The ventilator performance has been tested with MATLAB/Simulink tool with the aid of a Proportional Integral Derivative (PID) Controller and a promising result has been obtained.
Keywords: Ventilator, Resistive, Proportional Integral Derivative, COVID-19

1. INTRODUCTION

Ventilators are modernized microchip-controlled machines; however, patients can likewise be ventilated with a basic, hand-worked pack valve cover [1]. Ventilators are mainly utilized in concentrated consideration medication, home consideration, and crisis medication (as independent units) and in anesthesiology (as a part of a sedation machine) [2-3]. Ventilators are now and then called "respirators", a term usually utilized for them during the 1950s (especially the "Bird respirator"). Be that as it may, contemporary emergency clinic and clinical phrasing utilizes "respirator" to allude to a defensive face-veil [4-5].

In its easiest structure, a cutting edge positive pressing factor ventilator comprises of a compressible air repository or turbine, air and oxygen supplies, a bunch of valves and tubes, and an expendable or reusable "patient circuit" [6]. The air repository is pneumatically compacted a few times each moment to convey room-air, or by and large, an air/oxygen combination to the patient. On the off chance that a turbine is utilized, the turbine pushes air through the ventilator, with a stream valve changing strain to meet patient-explicit boundaries. When over pressure is delivered, the patient will breathe out inactively because of the lungs' flexibility, the breathed-out air being delivered normally through a single direction valve inside the patient circuit called the patient complex.

Ventilators may likewise be furnished with checking and alert frameworks for patient-related boundaries (e.g., pressing factor, volume, and stream) and ventilator work (e.g., air spillage, power disappointment, mechanical disappointment), reinforcement batteries, oxygen tanks, and controller. The pneumatic framework is these days regularly supplanted by a PC controlled turbopump [7].

Current ventilators are electronically constrained by a little inserted framework to permit careful transformation of pressing factor and stream attributes to an individual patient's requirements [8]. Adjusted ventilator settings additionally serve to make ventilation more decent and agreeable for the patient. In Canada and the United States, respiratory specialists are liable for tuning these settings, while biomedical technologists are answerable for the upkeep. In the United Kingdom and Europe, the administration of the patient's communication with the ventilator is finished by basic consideration attendants [9].

Since disappointment may bring about death, mechanical ventilation frameworks are delegated life-basic frameworks, and safeguards should be taken to guarantee that they are exceptionally solid, including their force supply. Ventilatory disappointment is the powerlessness to support an adequate pace of $CO2$ end to keep a steady pH without mechanical help, muscle weariness, or terrible dyspnea.[10] Mechanical ventilators are consequently painstakingly planned so that no single mark of disappointment can imperil the patient. They may have manual reinforcement components to empower hand-driven breath without power, (for example, the mechanical ventilator incorporated into a sedative machine). They may likewise have wellbeing valves, which open to climate without ability to go about as an enemy of suffocation valve for unconstrained breathing of the patient [11]. A few frameworks are additionally outfitted with packed fuel tanks, air blowers or reinforcement batteries to give ventilation if there should arise an occurrence of force disappointment or faulty gas supplies, and strategies to work or call for help if their components or programming come up short.

2. MATHEMATICAL MODELLING

— **How is it work**

At a normal patient breath, the reference resistance from the potentiometer R is given as input. When the patient breathing increases or become deep, the resistance of the belt increases because of that the voltage given to the solenoid valve increases so that more air volume will get out from the solenoid valve. The solenoid valve is attached to oxygen compressor and the amount of air volume is controlled by the solenoid valve. The block diagram of the ventilator system is shown in Figure 1 below.

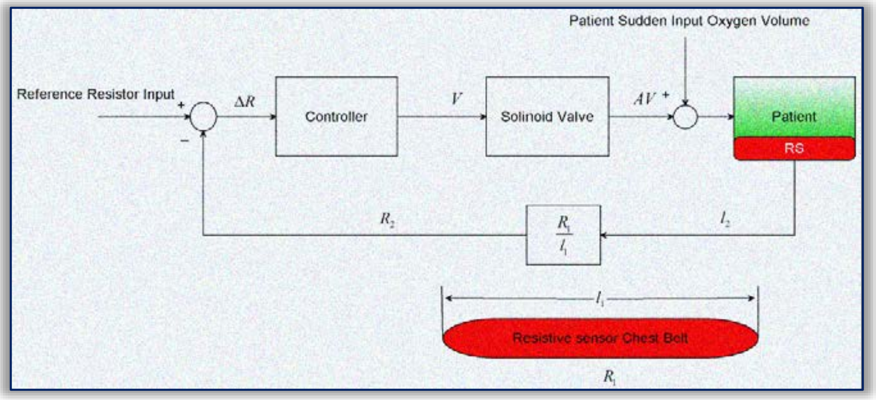

Figure 1. Block diagram of the ventilator system

— **Resistive Sensor Chest Belt**

The resistive chest belt is simply a belt with a resistor attached on it and when the patient air breath increases the belt expands and the resistor length will be changed and also the resistance of the belt increases.

— **Resistive Belt Modeling**

The resistance of the belt changes when the patient air volume inhale increases. The change in resistance occur because of the change in length of the belt.

From the equation of resistance

$$R = \frac{\rho l}{A} \quad (1)$$

The resistivity and the area are constants

$$\frac{R}{l} = \frac{\rho}{A} = C \quad (2)$$

When the patient breathing increases the length of the resistive belt increases and becomes

$$\frac{R_1}{l_1} = \frac{R_2}{l_2} \quad (3)$$

From this equation we can simply get the new patient volume resistance as

$$\frac{R_1 x l_2}{l_1} = R_2 \quad (4)$$

— **Modelling of the Solenoid Valve**

The solenoid valve is the device that controls the air flow from the oxygen compressor to the patient. Let the solenoid valve represented by first order system

$$G(s) = \frac{5}{10s + 10} \quad (5)$$

where G(s) is the transfer function between the input voltage and output air volume.

— **Tidal Volume (TV)**

It is the measure of air that can be breathed in or breathed out during one respiratory cycle]. This portrays the elements of the respiratory focuses, respiratory muscles and the mechanics of the lung and chest divider. The typical grown-up esteem is 10% of indispensable limit (VC), around 300-500ml (6-8 ml/kg); however, can increment up to half of VC on breathing incapacity happen. The relationship between the patient inhale air volume and the belt length is assumed to be linear. The chest diameter for adult person with age b/n 30-35 and height of 1.55 meter is 0.8 meter.

For normal berating the relationship becomes

$$\frac{l}{AV} = \frac{0.8}{500} = 0.0016$$

$$l = 0.0016AV$$

— **Ventilator air Duct Design**

The air duct acts as air input and output and this system acts as a ventilator and the system diagram is shown in Figure 2 below.

The system has 2 check valves to control air flow in and air flow out as shown in the Figure 2 above.

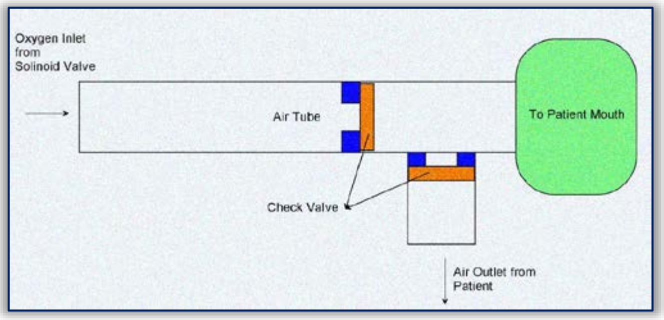

Figure 2. Ventilator air duct model

3. PROPOSED CONTROLLER DESIGN

A PID controller is an instrument utilized in mechanical control applications to direct temperature, stream, pressing factor, speed and other cycle factors. PID (corresponding vital subordinate) regulators utilize a control circle input instrument to control measure factors and are the most precise and stable regulator.

PID control is a grounded method of driving a framework towards an objective position or level. It's a basically universal as a method for controlling temperature and discovers application in heap synthetic and logical cycles just as robotization. PID control utilizes shut circle control input to keep the genuine yield from a cycle as near the objective or setpoint yield as could be expected.

4. RESULT AND DISCUSSION

— System Parameters

Copper has a resistivity of 0.0171 Ohm · mm²/m and is, therefore, one of the best conductors for electric current and mentioned above the belt length is 0.8m and let the belt area becomes 40 mm2. Therefore, the normal air volume resistance becomes

$$R_{normal} = \frac{\rho l}{A_{belt}} = \frac{(0.0171\,ohm)(0.8\,m)}{40\,mm^2} = 0.000342$$

Therefore, the setpoint resistance becomes 0.000342

— Simulink Block Diagram

The Simulink block diagram of the mechanical ventilator is shown in Figure 3 below. Here in this system, a PID controller with auto tuner system, a solenoid valve transfer function, a sudden patient air volume, air volume to change in belt length, length to resistance converter, inhale air volume scope and output resistance scope blocks are shown below.

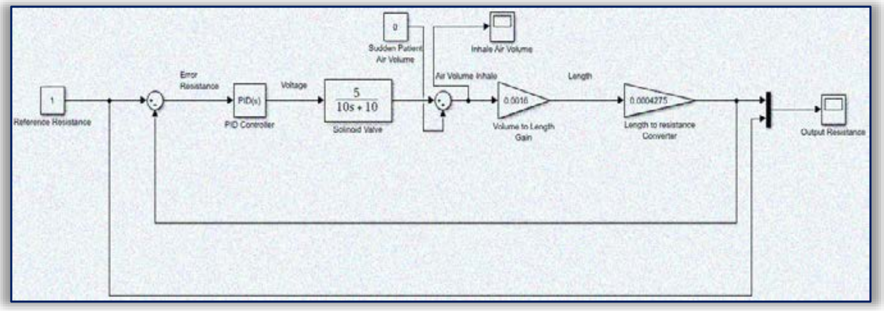

Figure 3. Simulink block diagram

— Simulation of the Actual Belt Resistance to Reference Resistance with Patient Normal Breathing

The simulation result of the patient normal breathing for a given reference resistance output actual resistance and air volume inhale are shown in Figure 4 and Figure 5 respectively.

The simulation result shows that the reference and actual resistances are the same and there is no error resistance signal and the solenoid valve will continue to give the patient an amount of air volume of 500 ml of oxygen volume.

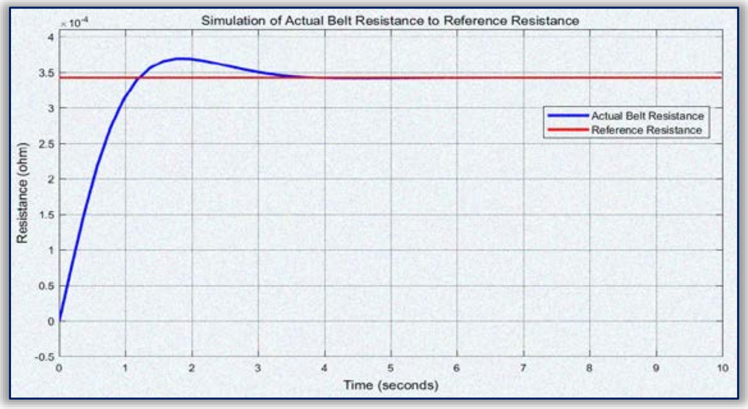

Figure 4. Simulation result of the actual and reference resistances

— Simulation of the Actual Belt Resistance to Reference Resistance with Patient Sudden Air Volume Inhale

The simulation result of the patient sudden air volume inhale of 300 ml for a given reference resistance output actual resistance and air volume inhale are shown in Figure 6 and Figure 7 respectively.

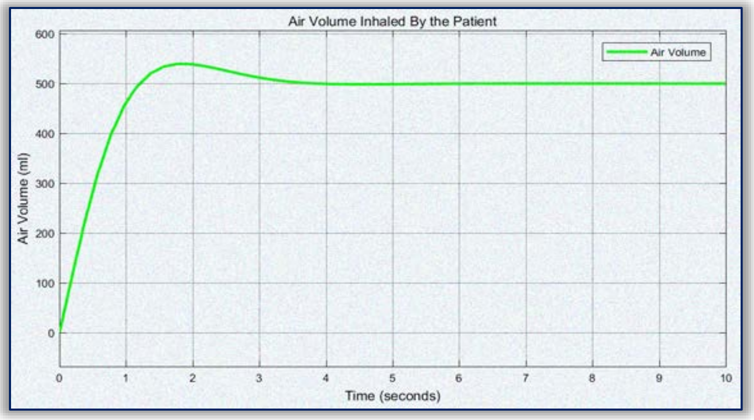

Figure 5. Normal breathing air volume

The simulation result shows that the actual resistances increases because the increase in chest diameter or length of the belt and there is an error resistance signal which adjusted the solenoid valve to give the patient a sufficient oxygen volume and the patient will continue to breath with an air volume of 800 ml of oxygen.

5. CONCLUSION

In this paper, a resistive belt sensor based mechanical air ventilator has been designed for COVID-19 patients successfully. The resistive belt sensor attached to the patient chest to sense the resistance of the belt while the patient breathes. PID controller have been implemented to the mechanical ventilator in order to test the response of the system. The system response test has been done with the aid of MATLAB/Simulink for a patient with normal breathing and sudden breathing change. The simulation results shows that the system has a better response and for the future work the system performance may be improved if another controller implemented.

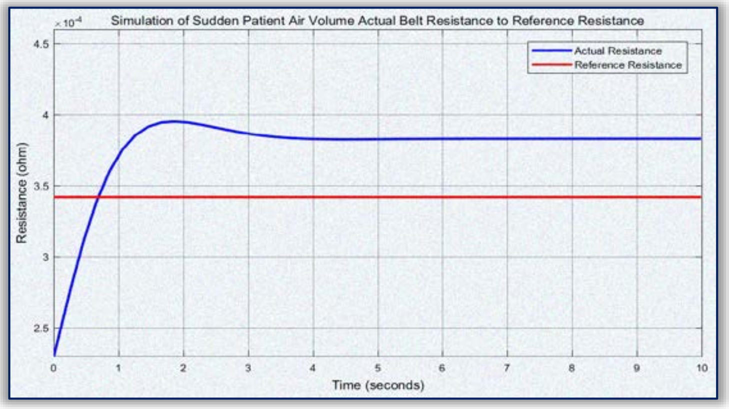

Figure 6. Simulation result of the actual and reference resistances for a sudden air volume inhaled by the patient

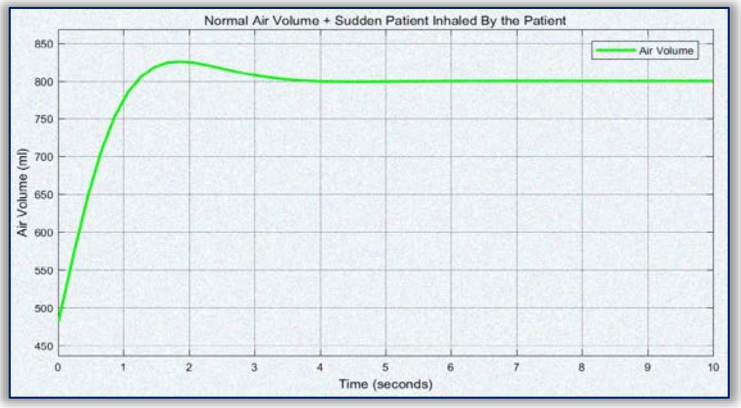

Figure 7. Sudden breathing air volume

References

[1] Tiruvoipati R, Botha J. Fighting a pandemic with mechanical ventilators. Intern Med J. 2020;50(8):1019-1020
[2] Wunsch H, Hill AD, Bosch N, et al. Comparison of 2 Triage Scoring Guidelines for Allocation of Mechanical Ventilators. JAMA Netw Open. 2020;3(12):e2029250
[3] King WP, Amos J, Azer M, Baker D, Bashir R, et al. (2020) Emergency ventilator for COVID-19. PLOS ONE 15(12): e0244963
[4] Ferguson NM, Laydon D, Nedjati-Gilani G, Imai N, Ainslie K, Baguelin M, et al. Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand. Spiral Imp Coll London's Repos. 2020; 1–20
[5] Jiri Hromadka, Nurul N. Mohd Hazlan, Francisco U. Hernandez, Ricardo Correia, A. Norris, Stephen P Morgan, Sergiy Korposh, Simultaneous in situ temperature and relative humidity monitoring in mechanical ventilators using an array of functionalised optical fibre long period grating sensors, Sensors and Actuators B: Chemical, Volume 286, 2019, Pages 306-314.
[6] Badnjevic, Almira; Gurbeta, Lejla; Jimenez, Elvira Ruiz, Iadanza, Ernesto;, Technology and Health Care, vol. 25, no. 2, pp. 237-250, 2017
[7] Chatburn R.L. El-Khatib M. Mireles-Cabodevila E. A taxonomy for mechanical ventilation: 10 fundamental maxims. Respir Care. 2014 Nov; 59: 1747-1763
[8] Esteban A. Ferguson N.D. Meade M.O. et al. Evolution of mechanical ventilation in response to clinical research. Am J Respir Crit Care Med. 2008; 177: 170-177.
[9] Hick JL, O'Laughlin DT. Concept of operations for triage of mechanical ventilation in an epidemic. Acad Emerg Med. 2006;13(2):223–9.
[10] Anne Battisti, Didier Tassaux, Jean-Paul Janssens, Jean-Bernard Michotte, Samir Jaber, Philippe Jolliet, Performance Characteristics of 10 Home Mechanical Ventilators in Pressure-Support Mode, Chest, Volume 127, Issue 5, 2005, Pages 1784-1792.
[11] Branson R.D. Chatburn R.L. Technical description and classification of modes of ventilator operation. Respir Care. 1992; 37: 1026-1044

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665