INVESTIGATION OF VENTILATOR WORKING PRINCIPLE AND DESIGNING WITH EQUIPMENT TO BE USED FOR RAPID PRODUCTION

Aydın GÜLLÜ[1], Kemal AKKUŞ[2], Özcan ÇETİNKAYA[3]
[1] *Trakya University Vocational School of Ipsala*
[2] *Trakya University Institute of Science*
[3] *Trakya University Vocational School of Keşan*

Abstract
In some epidemics, respiratory support devices are needed more in the recovery process of patients. Health equipment is inadequate in the face of sudden outbreaks. The aim of this study is to examine the working principle of the ventilator device used in artificial respiration intervention in living things with diseases such as lung disease or respiratory failure and to help researchers by researching the equipment to be used for rapid production. Thus, information on the rapid production of a critically important device that can serve more people in possible outbreaks will be provided.

Keywords: Ventilator Design, Working Principle of Ventilation

INTRODUCTION

As it is known, living beings take in oxygen (O2) while breathing and release carbon dioxide (CO2) into the atmosphere while exhaling. The whole process of breathing (inspiration / expiration) is called respiratory function. While respiration occurs on its own in healthy living things, it can be performed artificially in living things with diseases such as lung disease and respiratory failure. The device that performs breathing artificially is called a ventilator, and this process is called ventilation[1].

Ventilation is carried out in 3 different ways. Negative Pressure Ventilation, Positive Pressure Ventilation and High Frequency Ventilation. 5 magnitudes play an important role in the ventilation process. These; Pressure, Volume, Flow, Inspiratory: Expiratory ratio (I: E) and Time. Since each patient who has lost the ability to breathe on his own needs different types of ventilation, these five sizes, which perform different tasks in ventilators, perform ventilation according to the needs of the patient..

EXPOSITION

BASIC CONCEPTS

Ventilation

If we simply define ventilation, we can say that it is the movement of oxygen into and out of the lung. The main purpose of ventilation is to take the rich oxygen in the air into the lungs and to expel it in the air containing carbon dioxide in the lung. An example ventilator is shown in the figure 1.

***Fig 1**. A Sample Ventilatör Machine*

Respiration

The movement of oxygen taken through the respiration through the membrane is called respiration and it is divided into two.

1-External Respiration: The movement of oxygen from the lungs to the bloodstream and carbon dioxide from the circulation to the alveoli (air sacs) is called external respiration.

2-Internal Respiration: The movement of oxygen from blood into the cell and carbon dioxide out of the cell and into the circulation is called Internal Respiration.

Inspiration

During ventilation, the entry of air into the lungs is defined as breathing. Inspiration is provided by the expansion of the chest cavity.

Expiration

It is defined as the exit of air from the lungs and is normally a passive event. During expiration, the respiratory muscles relax, the volume of the thoracic cavity decreases, and respiratory air is pushed out of the alveoli[2].

CONTROL PARAMETERS

Pressure

Gas movement occurs with pressure differences during ventilation. Here, with the pressure differences created consciously, the volume required for gas exchange reaches the alveoli, depending on the patient's lung compliance (volume change against unit pressure change) and airway resistance.

Volume

As in normal breathing, the main purpose in mechanical ventilation is to provide the necessary volume for proper minute ventilation. During ventilation, the volume is dependent on the flow rate determined by time and pressure.

If the volume is adjusted as a function of time, pressure becomes compliance dependent. Volume is independent pressure dependent variable. For the ventilator to actually operate with volume control, the volume must be measured directly. Many ventilators cannot measure volume directly; calculates from the amount of current over a certain time and uses the volume as a limiting variable.

V: Lung Volume, C: Compliance, P: Pressure

$P = V / C$

$V = P \cdot C$

Time

In all mechanical ventilation techniques used in practice, there is a respiratory rate (frequency) and respiratory cycle duration calculated by the minute / frequency ratio. Respiratory cycle time is defined as the time elapsed from the beginning to the end of breathing.

Current

The flow, which has two components, namely speed and model, expresses the movement of the gas in a certain period of time during ventilation.

VENTILATION METHODS

Negative Pressure Ventilation

During this application, the movements of the respiratory muscles are imitated, and ventilation is allowed according to the physiological condition of the patient. An example of this type of ventilator is a tank ventilator or iron lung. The prototype of negative pressure ventilators are cylindrical tanks called steel lung or tank respirators, which allow the thorax to expand with the negative pressure applied to the outside of the thorax and take in the entire body of the patient except the head and neck.

Advantages: These ventilators have advantages in terms of durability, ease of use and safety. It provides an advantage in that they do not require intubation and moisturizing. In this method, patients can talk and feed easily.

Disadvantages: The most important disadvantage is that tank ventilators are big and bulky.

Positive Pressure Ventilation

The various limitations of negative pressure ventilation have led to the development of devices for positive pressure ventilation. In positive pressure ventilation, a pressure difference is created between the alveoli and the airway by applying a pressure above atmospheric pressure to the ventilator and airways. Thus, due to the pressure difference that occurs, respiratory air is delivered to the alveoli. Therefore, the pressure generated in the upper airways is equal to the sum of the elastic contraction of the lung and chest wall and the pressures required to overcome airway resistance.

In mechanical breaths, breathing is initiated or triggered by the ventilator, controlled and terminated by the ventilator. The entire work of breathing is covered by the ventilator. In assisted breaths, the breath is triggered by the patient, but the control and termination of the breath is determined by the ventilator instead of the patient. In the third form of breathing, spontaneous breathing, each breath is completely determined by the patient. However, spontaneous breathing can be supported with a predetermined pressure when desired.

Today, positive pressure ventilation is used as a routine mechanical ventilation technique in applications.

High Frequency Ventilation (HFV)

High frequency ventilation is actually an application that works on the principles of positive pressure ventilation. However, the minute volume required for the ventilation of the patient is provided by using low ventilation volume and high ventilation rates. There are 3 basic models developed for this.

1-High frequency positive pressure ventilation (High frequency Positive Pressure Ventilation = HFPPV): In this type of ventilation, the respiratory rate is 60-100 / minute.

2-High frequency jet ventilation (High frequency jet ventilation: HFJV): Here, the respiratory rate is 100-600 / minute.

3-High frequency oscillation (HFO): Frequency is approximately 4000 / minute over 1000 per minute.

Design Units

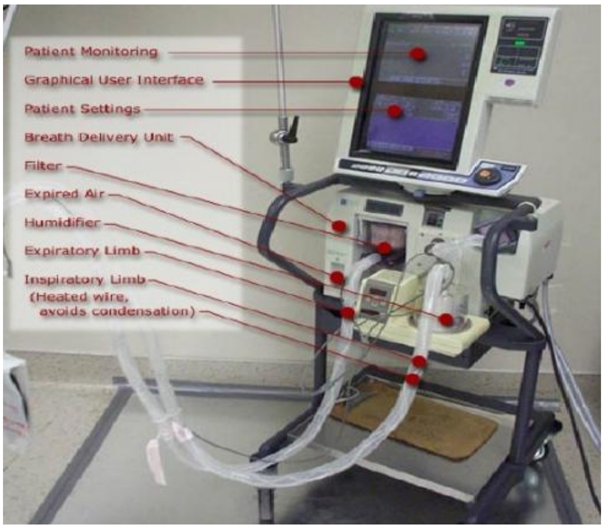
Control and Monitoring Unit

An electronic system is required in order for the control and imaging system to make the necessary warnings to the user and to see the data from the system and the patient on the display. This system is controlled by the microcontroller. Microcontroller evaluates the data coming from the system and the patient via sensors and transmits it to the control and imaging system. It also undertakes to save the settings made by the user and change them again when necessary.

Control can be done in two ways. The first is the simpler open loop control. The ventilator will operate in line with the parameters set in this method. However, in this control method, the device will not receive feedback neither on its own equipment nor on the patient. This method may pose some risks. For this reason, closed loop control method is preferred. It is more secure because it collects information on the patient and device[1,3].

Alarm Unit

The alarm system is a system that transmits the warnings from the pneumatic system or the patient to the user visually and audibly during the operation of the ventilator. The alarm system is under the supervision of the control PCB system and the control system receives its data through sensors connected to the pneumatic system. Each alarm has a different warning method. The audible warnings are transmitted by the loudspeaker and the buzzer, while the visual signs reach the user by the control display system.



Pneumatic Unit

This circuit consists of tubes and is the part that conveys the gas flow formed in the ventilator to the patient. In other words, the gas flow formed in the source first reaches the tubes from the internal circuits. From here, it is given to the patient through an external circuit. It consists of parts such as filter, regulation and humidification of the air. This unit can be created by using ready-made products used in many places.

The pneumatic system consists of the following units:

- Gas intake system
- Piston / cylinder system
- Inspiratory manifold system
- Patient breathing system
- PEEP / CPAP system
- Exhalation system

Electronic Unit

The electronic unit provides the energy required for the ventilator to operate, evaluates the data coming from the pneumatic system and ensures that this data is transferred to the control and monitoring unit. It also manages the alarm unit. The electronic unit consists of the following parts[1,4].

- Power source
- Motor driver circuit
- Pressure sensor
- Pressure Switch
-Electro-printed circuit board (PCB) for control

1- Power Supply: The power supply can be electric, pneumatic or combined. The electrical energy used turns the ventilator on and off, keeps motors, electromagnetic systems, potentiometers, rheostats, bellows, pistons, and alarm systems activated. All these circuits are systems that control the gas flow. Electronic circuits that program the air flow to the patient in all microprocessor ventilators work with electrical power.

Electronic circuits that program the gas flow to the patient in all microprocessor ventilators work with electrical power.

2- Motor Driver Circuit: The motor is controlled by the BD (breath distribution) part of the controller PCB. The motor encoder continuously monitors the speed and direction of rotation of the motor. The motor control circuit also controls the driver circuit according to the data received from the encoder. The motor driver circuit provides the movement of the motor with the energy it receives from the power source and the data it receives from the control circuit.

3- Pressure Sensor and pressure switch It is the unit in which all parameters of the pneumatic system in the ventilator are evaluated, measured and controlled.

• Pressure Transducer Interface: It is the circuit that examines inspiratory / atmospheric pressure, expiratory pressure, cylinder pressure values during respiration.

• Solenoid Driver Circuit: It is the unit that determines whether the solenoid valves in the ventilator are activated or not.

• Audible Alarm Driver Circuit: It is the circuit that continues the alarm circuit that can make audible warning.

• PEEP Driver Circuit: It is the circuit that drives the output of the wavelength modulated signals required for the PEEP pump to operate.

• Thermistor / Interface Circuit: It is the circuit consisting of the transducer and thermistor mounted on the PCB. Inspiratory, expiratory pressure transducer and temperature sensor are located on this circuit.

• Safety Valve Circuit: If the expiratory pressure of the patient exceeds 115 cmH_2O, the safety valve must be opened to the atmosphere. The opening of this valve is managed by a software specified controller. In software, the normal value is determined as 92 cmH_2O.

• Fan Circuit: It is the circuit that detects whether the fan is active or not. The fan should be on while the ventilator is running.

• Heater Circuit: It is the circuit that controls the expiratory heaters. The working temperature of the heaters should be 50 ° C.

• Tachometer Circuit: It is the circuit that measures the movement speed of the piston.

4- Control PCB: There are two parts of the controller PCB. These are breath delivery (BD) and control display system (UI). These sections are physically separated, with each section on one half of the PCB. Each section contains its own microprocessor and external memory.

• BD (Breath Delivery) Unit: It is the section where the controls of the control PCB unit are made for the pneumatic system.

• UI (Control and Display System) Unit: It is the control unit where user adjustments and user visual data are processed[4-7].

CONCLUSION

In this study, the necessary equipment's to produce a ventilator device in case of intense need are mentioned. The main structure of a simple ventilator can be produced with suitable connections by supplying equipment already used in many sectors. By using a microcontroller and some electronic elements to control this equipment, a ventilator that can be used for patients can be produced. Developed in recent years, 3d printer, open source microcontroller software (Arduino) has made operations even easier.

REFERENCE

[1] T.C. Milli Eğitim Bakanlığı, 'Yapay Solunum (Ventilatör) Cihazlari', BİYOMEDİKAL CİHAZ TEKNOLOJİLERİ (2012).
[2] Doç. Dr. Öner DİKENSOY, 'Mekanik Ventilasyon Nedir?', 8. Ulusal İç Hastalıkları Kongresi (2006).
[3] Hasan GÜLER, 'Programlanabİlİr Lojİk Kontrolör İle Mekanİk Ventİlatör Tasarimi ', Fırat Üniversitesi (2007).
[4] Hasan GÜLER, İbrahim TÜRKOĞLU, and Fikret ATA, 'Mekanİk Ventİlasyon Ve Akilli Kontrol Teknİklerİ', Fırat Üniversitesi (2011).
[5] 'Mekanik Ventilatör Tasarım Metotları', Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 26 (2010).
[6] Hakan GÜNEN, and Özkan KIZKIN, 'Ards'de Mekanik Ventilasyon Prensipleri', Tüberküloz ve Toraks Dergisi 52 (2004), 199-206.
[7] Arthur S. Slutsky, 'History of Mechanical Ventilation from Vesalius to Ventilator-Induced Lung Injury', American Journal of Respiratory and Critical Care Medicine, 191 (2015), 1106-15.