Mixed Pressure Control Innovation of Oxygen and Air Pressure in Ventilator with Safety Valve

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Abstract. The medical gas in the ventilator is very influential in maintaining patient survival so that the gas must be sterile, have high purity and have a stable pressure, with a value of no more than 5 bars. To maintain the stability of this pressure, a control device for oxygen and air pressure on the ventilator is designed with a safety valve. Pressure control on this ventilator mixing tube uses an ATMega328P microcontroller to drive the Pneumatic Valve as a safety device. Furthermore, the pressure will be read by the MPX 5700 AP sensor. After that, the results of a pressure reading of 1 to 5 bars are displayed on the seven-segment display. The comparison of the pressure difference between the pressure read by the sensor and displayed on the manometer resulted in the highest error of 4% and the lowest error of 2.37%. Whereas in the relay contact test, the safety valve worked well, and the error value was 3.29%. The difference in error values is considered completely safe to use.

Keywords: Medical Gas Pressure, Safety Valve, Ventilator Mixing Tube

1. Introduction

The human body is an extraordinary machine containing many vital organs that operate for different bodily functions. One of the essential parts of the organ is the lungs. The lungs are a vital part of the human body to regulate breathing from inspiration to expiration. Lung disease is not only caused by smoking but can also be from surrounding dust, unhealthy lifestyles and infectious diseases such as tuberculosis and others. When the condition is chronic, the person will have difficulty breathing and may have to use an assistive device, a ventilator [1].

A ventilator is a device to aid breathing for those who cannot breathe normally. As for the type, the ventilator can be used either invasively or non-invasively [2]. In the ventilator, there is a medical gas supply in the form of oxygen and air pressure which will be mixed into the humidifier to be warmed before entering the patient's body [3].

While connected to the ventilator, a conscious patient cannot speak or eat by mouth because the tube is inserted into the throat. In general, the patient will feel uncomfortable and sometimes fight the air exhaled by the ventilator and make the ventilator function less effective. During the use of a ventilator, several side effects can be caused, one of which is lung injury and air leakage into the cavity outside the lungs (pneumothorax). Pneumothorax or leaky lungs is a condition where air collects in the pleural cavity, a thin cavity bounded by two pleural membranes between the lungs and the chest wall. The air in the pleural cavity can occur as a result of a gap due to injury to the chest wall or a tear in the lung tissue. As a result, the air can compress the lungs and cause the lungs to collapse [4]. In this case, the primary role of medical gas is very influential. Thus, the ventilator is completed with a safety valve.
For safety valves, the pneumatic valve was used due to high pressure gas. Also, the safety valve was intended to remove the excess gas pressure in the cylinder automatically [5] so that the medical officers do not have to do manual checks as in previous studies.

In a study by [6], monitoring of the pressure at the gas center was carried out using two gas storage tubes. The sensor used is the MPX5700 sensor. Monitoring of pressure at the gas center using two storage tubes (primary and secondary tubes). The error results obtained are 0.1% for the 600 KPa pressure measurement, 0.1% for the 500 KPa measurement, 0.25% for the 400 KPa measurement, -0.8% for the 300 KPa measurement, 0.6% for the 200 KPa measurement and 0.6% on the measurement of 150 KPa against a comparator (Digital Pressure Meter). The drawback is that medical gases are measured only at oxygen pressure, and the errors do not meet safety criteria. In contrast, the advantage of this research is that it has used a solenoid valve for the replacement of the primary to secondary pressure tube when the pressure read by the sensor is less than 150 KPa.

Subsequent research was carried out by [7], who made a monitoring tool for the pressure of Oxygen (O2), Nitrous Oxide (N2O), Medical Compressed Air (Breathing Air) on central gas with a digital system. The MPX 5700 AP sensor is used as a pressure reader. The error value obtained at each measurement point, namely at a pressure of 300 Kpa is 4.46%, a pressure of 400 Kpa is 0.81%, a pressure of 500 Kpa is 1.61%, and at a pressure of 600 KPa, an error of 1.86% is obtained. The disadvantage of the tool is that the pressure measurement is only at a value of 300 - 550 Kpa. Then the buzzer alarm is also a reference for the occurrence of low pressure and high pressure. While the advantages of this study are that at each point tested, the error value obtained has entered into the criteria for a medical gas pressure of no more than 5%.

Based on the identification of the problem above, the writer will make the pressure control innovation of the mixture of oxygen and air pressure, equipped with a safety valve on the ventilator to be able to maintain the stability of the pressure in the gas mixing tube in the ventilator. The data will be processed by ATMega 328P, and the pressure sensor used is the MPX 5700 AP. The advantage of the tool that the author designed is that the MPX 5700 AP sensor will ensure that the pressure value in the tube does not exceed this rated value. However, if there is a gas pressure that exceeds the value of 5 bar, the pressure will be released automatically through the safety valve on the appliance. The type of safety valve used is a pneumatic valve because this valve is specifically for the use of high-pressure gases [8].

2. Methodology

2.1. Flowchart

Based on Figure 1, the process starts from the initialization of the program, then added the input gas from the air compressor. After that, the air will automatically enter the mixing tube, and in this tube, the incoming pressure will be read by the pressure sensor of MPX 5700 AP [9], which will then be displayed on the seven-segment. If the incoming and received pressure on the tube is <4.85 bar, it means that the process cannot be executed, instead, go back to the process of filling the input gas. However, if the incoming pressure is > 4.85 bar, the valve will automatically open, and the excess gas in the tube will be flushed out. The phenomenon is a sign that the process is running well and the whole process has been completed.
2.2. Hardware Design

Hardware design is the electronic circuits arranged in a connected operation. The designed hardware is the microcontroller ATMega 328P, the relay circuit, the MPX 5700 AP circuit, and the seven-segment display circuit.

a) Seven-Segment Circuit

The seven-segment series designed can be seen in Figure 2. The seven-segment circuit is used as a display on the device, which will later display the reading from the pressure sensor. In this seven segments circuit, the seven-segment common anode is used. The Seven Segment circuit is composed of several electronic components of IC TM1637, capacitors, and resistors, which will be output from the seven-segment circuit connected to pins D9 and D8 in the Arduino circuit acted as a display of pressure sensor readings.
b) Sensor Circuit
The pressure sensor circuit used the MPX 5700 AP sensor with the sensor output connected to the Arduino analog pin on A0. This circuit functions as a sensor to read the pressure in the mixing tube and displayed on the seven-segment display. The circuit can be seen in Figure 3.

c) DC Relay Circuit
The DC relay circuit functions as a controller of the safety valve. The electronic components used are NPN transistors, 5 Volt DC relays, resistors, diodes, and LEDs. The relay circuit is connected to ATMega 328P on pin PD4. The following is a schematic of a DC relay circuit as shown in Figure 4.

d) Microcontroller Circuit
The ATMega 328 P circuit functions as the brain for processing the incoming data from the sensor and giving the order for the process to be executed [10]. The type of IC used in microcontroller circuit is the ATMega 328P IC with Arduino IDE programming settings. In the ATMega 328P circuit, there are 6 analog pins and 13 digital pins. For pins that are available on ATMega 328P, not all pins will be used. In the display circuit using digital pins 8 and 9, for pressure sensor circuits using analog pin A0, for relay circuits using digital pin 3. ATMega 328P circuit schematic can be seen in Figure 5.
2.3. Tool Design
The design of the pressure control device for the gas mixing is in Figure 6 and Figure 7.

Descriptions of Front View:
a. Seven segment display.
b. Gas input to the cylinder.
c. Mixing tube.
d. MPX 5700 AP hose.
e. Digital pressure meter.

Descriptions of Side View:
a. Input gas source.
b. Output safety valve.

3. Result and Discussion
3.1. Test Results
The difference in comparison test is carried out to determine the amount of pressure difference between the value on the seven-segment display and the value displayed on the digital pressure gauge (digital manometer). The pressure point measured is a value of 1 to 5 bars. The following are the results of the tests.

Table 1. Results of the Difference Testing Error at Each Pressure

| No | Measurement Point | Average | Error (%) |
|----|-------------------|---------|-----------|
| 1  | 1,00              | 0.95    | 3.75      |
| 2  | 1,50              | 1.45    | 3.33      |
| 3  | 2,00              | 1.90    | 2.37      |
| 4  | 2,50              | 2.40    | 4.00      |
| 5  | 3,00              | 2.90    | 3.08      |
| 6  | 3,50              | 3.40    | 2.86      |
| 7  | 4,00              | 3.85    | 3.62      |
| 8  | 4,50              | 4.40    | 3.33      |
| 9  | 5,00              | 4.80    | 3.10      |
From Table 1, the error value between the seven segments and the manometer is a pressure of 1-5 bars with the highest error of 4% and the lowest error of 2.37%. In testing the difference in comparison at each pressure, the error value of 1-5 bars is still within the allowed limit, which is no more than 5% [11]. The error value was caused by a human error when giving the input gas manually into the mixing tube. Due to changes in the reading that was too fast in the tool and the comparison device so that an error occurred in retrieving data. Hence, on the digital manometer, the reading value was displayed when the pressure rose, or decreasing is not linear because of the specifications of the digital manometer.

3.2. Contact Relay Test Results

For testing on relay contacts, it is carried out when the relay is active or working. Table 2 shows the results of the relay contact test.

| No | Seven segments (bar) | Manometer (bar) | Working / Inactive Valve |
|----|----------------------|-----------------|-------------------------|
| 1  | 4.86                 | 4.70            | Working                 |
| 2  | 4.86                 | 4.70            | Working                 |
| 3  | 4.86                 | 4.70            | Working                 |
| 4  | 4.86                 | 4.70            | Working                 |
| 5  | 4.86                 | 4.70            | Working                 |
| 6  | 4.86                 | 4.70            | Working                 |
| 7  | 4.86                 | 4.70            | Working                 |
| 8  | 4.86                 | 4.70            | Working                 |
| 9  | 4.86                 | 4.70            | Working                 |
| 10 | 4.86                 | 4.70            | Working                 |
| 11 | 4.86                 | 4.70            | Working                 |
| 12 | 4.86                 | 4.70            | Working                 |
| 13 | 4.86                 | 4.70            | Working                 |
| 14 | 4.86                 | 4.70            | Working                 |
| 15 | 4.86                 | 4.70            | Working                 |
| 16 | 4.86                 | 4.70            | Working                 |
| 17 | 4.86                 | 4.70            | Working                 |
| 18 | 4.86                 | 4.70            | Working                 |
| 19 | 4.86                 | 4.70            | Working                 |
| 20 | 4.86                 | 4.70            | Working                 |

Correction 0.16 100% Working
Error 3.29 %

From Table 2, testing on relay contacts is carried out when the relay is active or working. Obtained the sensor reading correction value is 0.16 bar and the error obtained is 3.29%. The error value is still below the allowable error threshold, which is not more than 5%. The error value was caused by a human error when giving the input gas manually into the mixing tube, then due to changes in the reading that was too fast in the tool and the comparison device so that an error occurred in retrieving data and on the digital manometer the reading value was displayed when the pressure rose, or decreasing is not linear because of the specifications of the digital manometer. Furthermore, for the safety valve test results, the results are that the valve can work with a 100% capacity.

3.3. Discussions

Based on the tests, the average pressure was 1 to 5 bars. In Figure 8, the error value between the seven-segment and the manometer is a pressure of 1 - 5 bar with the highest error of 4% and the lowest error of 2.37%. In testing, the difference in comparison at each pressure, the error value is still
within the allowed limit, no more than 5%. In Figure 9, the lowest average is at a pressure of 1 bar of 0.96 bar and the highest average is at a pressure of 4.85 bar of 4.86 bar.

![Error Graphic of 1 - 5 Bars Pressure](image)

**Figure 8.** Pressure Comparison Error of 1-5 Bars Graph

![Comparison Graphic of the Average value of 1 - 5 Bars Pressure](image)

**Figure 9.** Average Comparison Graph

For testing on relay contacts, it is carried out when the relay is active or working. The sensor reading correction value was 0.16 bar, and the error was 3.29%. However, the error value is still below the allowed error threshold, which is no more than 5%. The error value was caused by a human error when giving the input gas manually into the mixing tube, then due to changes in the reading that was too fast in the tool and the comparison device so that an error occurred in retrieving data and on the digital manometer the reading value was displayed when the pressure rose, or decreasing is not linear because of the specifications of the digital manometer. Furthermore, for the safety valve test results, the results are that the valve can work with a 100% capacity.

From the data to test the pressure sensor, the data was collected 20 times from the pressure point 1 to 5 bar. The smallest error percentage value was 2.37%, while the largest error percentage was 4.00%. In testing the difference of each pressure, an error of 3.29% was obtained for the relay contact test. This value determines the level of measurement accuracy with the true value or the reading value of the comparator. The value obtained is different from the results of [6], that the largest error value was 4.46% while the smallest error value was 0.81%. In addition, research conducted by [7] showed the highest error value of 0.8% and the lowest value of 0.1%. Thus, in this study, the error results are smaller than in previous studies, and when the pressure reaches a maximum limit of 4.85 bar, the pressure will automatically be released instead of only shown on the display.

4. Conclusion

From the results of the tests, it can be concluded that innovations have been made to control oxygen pressure and air pressure on a ventilator equipped with a safety valve, and the device can function properly. The pressure sensor can read the pressure and is displayed on the seven-segment.
testing the pressure difference ratio, the error is less than 5%, where the highest error is 4%, and the lowest error is 2.37%. Meanwhile, in testing the relay contacts, an error of 3.29% was obtained. Safety valve can open and remove excess air in the mixing tube according to the instructions in the program. It is proven by the accuracy value of 100% in the relay contact test. When the pressure in the tube exceeds the value of 4.85 bar, the safety valve will remove excess gas in the mixing tube

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