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Design and Development of Flow Analyzer for Peak Inspiratory Flow (PIF) and Peak Expiratory Flow (PEF) Parameters

Andri Lazuardi Wahyu Pambudi, Endro Yulianto , and Levana Forra Wakidi 

Department of Electrical Engineering Poltekkes Ministry of Health, Surabaya, Pucang Jajar Timur Num. 10, Surabaya, 60245, Indonesia

Corresponding author: lep.forra@gmail.com

ABSTRACT This research study focused on the development and testing of a flow analyzer for monitoring the PIF (Peak Inspiratory Flow) and PEF (Peak Expiratory Flow) parameters in patients undergoing mechanical ventilation. These parameters are crucial for managing respiratory diseases like asthma and COPD. The study aims to ensure the accuracy of ventilator information provided to users by periodically testing and calibrating the ventilator using the flow analyzer. The primary contribution of this research is the utilization of the AFM3000 flow sensor to measure PIF and PEF parameters. By using this sensor, the researchers intend to enhance the accuracy of ventilator readings. The study was conducted in Volume Control (VC) mode with various VT (Tidal Volume) settings, ranging from 200 to 600 mL. Two different methods of data collection were employed to gather two sets of data. From the first data collection, the largest discrepancies in reading PIF and PEF values were found to be 3.49% and 2.99%, respectively. In the second data collection, the sensor exhibited a consistent reading for a constant flow of ± 0.1 LPM (Liters Per Minute), indicating stability. The research findings suggest that the AFM3000 flow sensor demonstrates good accuracy and stability in measuring PIF and PEF parameters. Furthermore, the sensor is sensitive and has a minimal delay, making it suitable for real-time graph display in the module. Overall, this study contributes to the field of medical technology by developing and validating a flow analyzer for monitoring PIF and PEF parameters in mechanical ventilation. The research showcases the potential of the AFM3000 flow sensor to improve the accuracy and reliability of ventilator information, ultimately benefiting patients with respiratory disorders.

INDEX TERMS PIF, PEF, LPM, Flow Analyzer.

I. Introduction

Lung ventilation is the process of delivering a gas mixture (air and oxygen) into the patient's lungs using a machine called a ventilator. The ventilator delivers the gas mixture to the patient at a specific pressure and flow rate [1][2][3][4]. Regular testing of the ventilator is necessary. One important parameter is the flow rate, both for the gas delivered to the patient (inspiratory flow) and the gas exhaled by the patient (expiratory flow) [5][6][7][8]. The Peak Inspiratory Flow (PIF) is a parameter that provides information about the maximum airflow delivered to the patient by the ventilator [9][10][11][12]. The PIF parameter typically measures the value of gas flow rate in liters per minute (LPM) [13][14][15]. The recommended PIF value is 60 LPM. However, it is possible that patients with specific needs may require a higher PIF value. For example, patients with respiratory distress may require a higher PIF value. A high PIF value can reduce pressure in the airways and shorten the inspiration time, potentially reducing oxygenation [9][16][17][18]. The Peak

Expiratory Flow (PEF) is the maximum airflow expelled from the lungs after a maximal inspiration, followed by a maximal expiration. Similar to PIF, PEF is measured in liters per minute [19][20][21][22]. PEF values can be used to measure maximum expiratory volume and provide an objective measure of symptom onset and exacerbation severity [13][23][24][25]. Exacerbation refers to a progressive increase in symptoms of breathlessness, cough, and decline in lung function in an individual [19].

In 2014, S. Natarajan conducted a study on a compatible peak flow meter device using a pressure sensor type TSCSNBN005PDUCV to convert pressure changes into voltage. The researcher tested the designed device by simulating human subjects blowing into a pipe using compressed air. The device was equipped with a smartphone that displayed differences in audible tones for different flow rates [13]. However, the reading range of this device is limited to 90-500 LPM, so it cannot be used for lower flow rate measurements. In 2016, Bogdan M. Ciurea et al.

conducted a study using a flow sensor called RAGL53, a type of Rota Yokagawa. The system created by the researchers consisted of a flow sensor, a flow rate device, and a data acquisition board running software to determine inspiratory and expiratory gas flow on a ventilator operating in VC-CMV mode (Volume Control-Continuous Mandatory Ventilation) [5]. However, the RAGL53 sensor is a rotameter-type sensor, which works optimally only when in a vertical position. Furthermore, in 2020, Mehwash Farooqui et al. conducted a study on a peak flow meter device to assist in monitoring patients with asthma. This study used a laser sensor, VL53L0X, where the peak flow meter device captured the incoming air flow, and the PEF value was obtained by the VL53L0X sensor and stored in NodeMCU ESP8266 [22]. However, the use of this sensor has low accuracy as it is a distance sensor. In the most recent study in 2021, Tomy Abuzairi et al. conducted research by developing an open-source ventilator tester using GFS131 as the flow-rate sensor. The purpose of creating this device was to produce a low-cost ventilator testing tool [26]. However, the researchers hope for future studies using different sensors to discover a ventilator tester with an even lower cost. Additionally, in the same year, Patrisius K. Ola et al. conducted research on a peak flow meter with sound output and Android monitoring. This study utilized the MPXV7002DP pressure sensor, which operates when the sensor receives air blowing, and measures the maximum air pressure during patient expiration [27]. Although it is equipped with Android monitoring, the display of this device still uses an Organic Light Emitting Diode (OLED) that only shows numerical results.

The studies mentioned above have some weaknesses. The research conducted by S. Natarajan has a reading range that is too broad, which means it cannot accurately measure flow values below 90 LPM or handle flow rates with negative values. Bogdan M. Ciurea's research utilized a rotameter type flow sensor, which is more suitable for vertical measurements but may not be as effective for other orientations. Tomy Abuzairi's research has a weakness according to the author, as they suggest that the research could have been conducted at a lower cost. Lastly, the research by Patrisius K. Ola only presents numerical data without including any flow rate graphs.

Based on the identified issues above, the author intends to conduct further research titled Design and Development of a Flow Analyzer for Peak Inspiratory Flow (PIF) and Peak Expiratory Flow (PEF) Parameters. This study aimed to develop a flow analyzer for PIF and PEF parameters with the results displayed on an LCD TFT screen in the form of graphs and numerical values. The main contribution of this research is testing the AFM3000 flow sensor to measure PIF and PEF parameters so that ventilators calibrated using the flow analyzer module provide accurate information to their users. This device is to

serve as a supporting device for ventilator maintenance in hospitals. Ultimately, the research contributes to the improvement of ventilator maintenance practices and patient outcomes in the field of respiratory care.

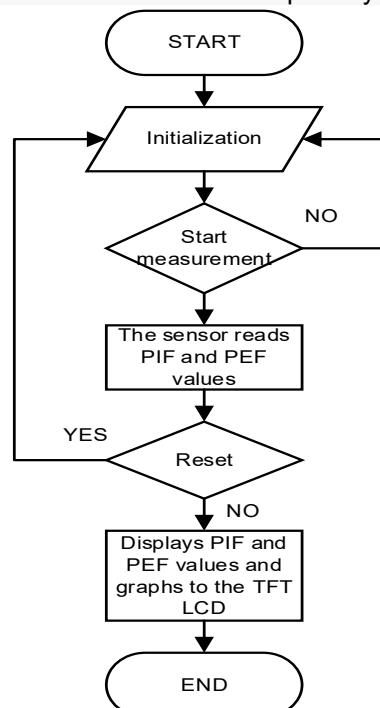


FIGURE 1 Flow chart

II. Materials And Methods

A. Experimental Setup

This research utilizes the AFM3000 flow sensor. The module that will be created will be connected to the ventilator, a reference device, and a test lung using a breathing circuit. The ventilator setting during data collection will be in VCV mode with VT values of 200, 300, 400, 500, and 600 mL. Data will be collected at each set point six times.

1) Materials And Tool

This research utilizes the AFM3000 flow sensor, Arduino Uno microcontroller, and TFT LCD display. During data collection, a ventilator unit, gas flow analyzer as a reference, and a test lung for simulating the lungs are required.

2) Experiment

In this study, after the Design was completed, data was collected from a ventilator. During the data collection process, the ventilator was set in Volume Control Ventilation (VCV) mode. The tidal volume settings in this study were 200, 300, 400, 500, and 600mL. Data was collected six times at each tidal volume setting. The data was obtained from the readings displayed on the LCD TFT module and the values displayed on the flow analyzer. The collected data will be processed to obtain sensor performance data.

B. The Diagram Block

In FIGURE 2 depicts the block diagram of the flow analyzer module. When the power button is turned on,

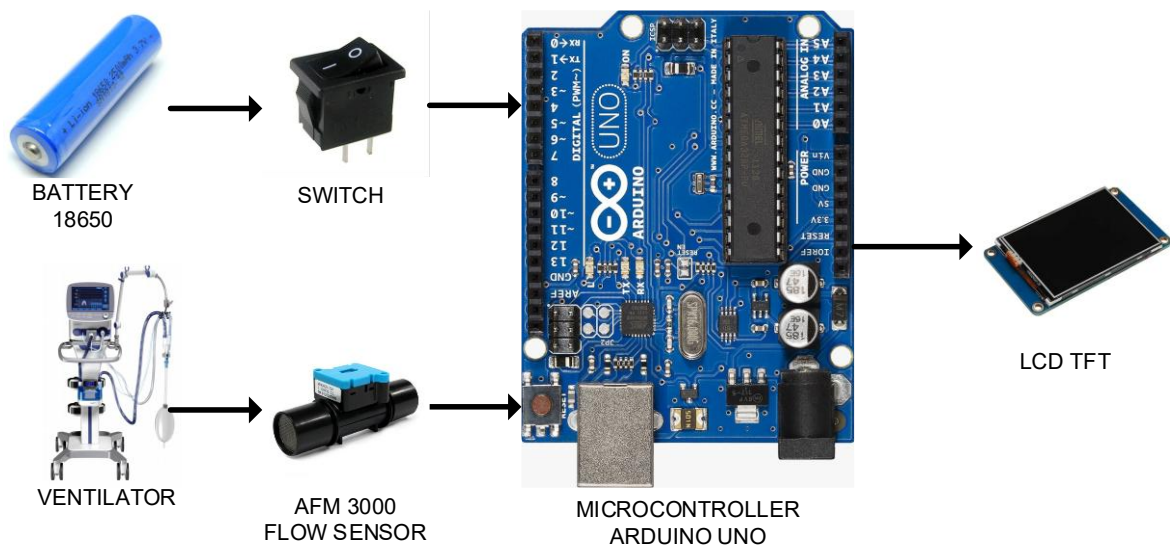


FIGURE 2 The block diagram of flow analyzer module.

the system will start functioning. The connected ventilator will begin operating and providing airflow. The airflow directed towards the patient and the airflow exhaled by the patient will be detected for their flow rates by the AFM3000 flow sensor. The Arduino Uno microcontroller IC will process the sensor readings. The output results from the microcontroller IC will be displayed on the LCD TFT screen, showing the numerical value and graphical representation.

C. The Flowchart

In FIGURE 1 represents the flowchart of the flow analyzer module. When the device is powered on, all systems will start functioning. Then, the microcontroller IC will initiate the initialization process. When the start button is pressed, the sensor will begin detecting the values of PIF and PEF based on the airflow passing through it. If the reset button is pressed, the sensor detection process will restart. However, if the reset button is not pressed, the values of PIF and PEF will be determined and displayed on the LCD TFT screen along with a graphical representation

III. Result

In this study, the module was tested by applying it to a ventilator. The LCD TFT on the module will display real-time flow rate graphs and also show the values of PIF and PEF read by the sensor.



FIGURE 3 Flow analyzer module

In FIGURE 3 represents the design of the flow analyzer module that has been created. The module's box details include two ports for input and output. The input port

receives air from the ventilator, while the output port is connected to the test lung. The device utilizes a 3.5-inch basic Nextion TFT LCD display to show real-time sensor readings in the form of values and graphs.

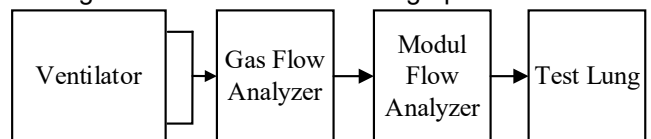


FIGURE 4 First method data acquisition diagram

In FIGURE 4 shows the installation of the flow analyzer module and the standard gas flow analyzer on the ventilator. The purpose of collecting this data is to obtain information that can be used to determine the level of error in the module, thus obtaining the accuracy of the AFM3000 flow sensor.

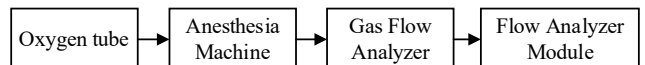


FIGURE 5 method data acquisition diagram

In FIGURE 5 represents the installation of the flow analyzer module and the standard gas flow analyzer on the anesthesia machine. The purpose of collecting this data is to obtain readings of a constant flow rate, in order to assess the stability of the AFM3000 flow sensor in measuring constant flow rate values.

TABLE 1 Result of PIF parameter

VT Setting (mL)	PIF (LPM)		Error (%)
	Average Design ± SD	Average Standard ± SD	
200	11,35 ± 0,15	11,75 ± 0,08	3,40
300	17,05 ± 0,15	17,67 ± 0,48	3,49
400	24,42 ± 0,07	24,37 ± 0,20	0,21
500	29,40 ± 0,42	30,23 ± 0,34	2,76
600	35,35 ± 0,83	36,13 ± 0,83	2,17

TABLE 1 presents the results of data acquisition for the PIF parameter. The table includes average calculations, standard deviations, and percentage errors of the sensor readings compared to the readings from the standard gas flow analyzer at each VT setting point. The highest error in sensor readings, compared to the reference device, for the PIF parameter is 3.49% at the VT setting point of 300 mL.

TABLE 2 Result of PEF parameter

VT Setting (mL)	PEF (LPM)		Error (%)
	Average Design \pm SD	Average Standard \pm SD	
200	22,43 \pm 1,12	22,10 \pm 1,37	1,51
300	29,27 \pm 1,28	29,95 \pm 1,42	2,28
400	34,08 \pm 1,17	35,13 \pm 1,82	2,99
500	37,28 \pm 0,61	37,38 \pm 1,09	0,27
600	38,50 \pm 1,10	38,13 \pm 1,26	0,96

TABLE 2 describes the results of data acquisition for the PEF parameter. The data presented in the table includes average calculations, standard deviations, and percentage errors of the sensor readings compared to the readings from the standard gas flow analyzer at each VT setting point. The highest error in sensor readings, compared to the reference device, for the PEF parameter is 2,99% at the VT setting point of 400 mL.

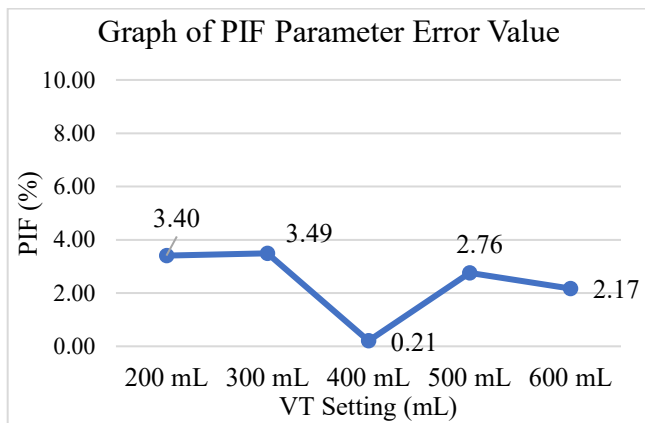


FIGURE 6 Error percentage PIF parameter

FIGURE 6 depicts a graph illustrating the percentage error in the AFM3000 flow sensor readings compared to the standard gas flow analyzer for the PIF parameter. The highest error recorded is 3.49%, while the smallest error is 0.21%. The percentage error varies at each VT setting point. This variation is attributed to the fluctuating flow emitted by the ventilator, leading to a considerable discrepancy between the module readings and the reference device values.

FIGURE 7 presents a graph illustrating the percentage error in the AFM3000 flow sensor readings compared to the standard gas flow analyzer for the PIF

parameter. The smallest recorded error is 0.27%, while the largest error obtained is 2.99%. The percentage error varies at each VT setting point. This variability is attributed to the fluctuating inspiratory and expiratory flows generated by the ventilator, leading to a substantial deviation in values between the module readings and the reference device.

In the data acquisition using the second method, the flow settings on the anesthesia machine were 4, 7, 11, 14, and 18 LPM. The module readings can be seen in the graph below.

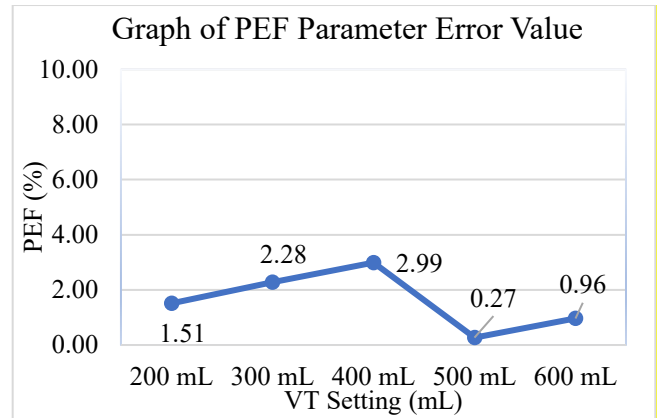


FIGURE 7 Error percentage PEF parameter

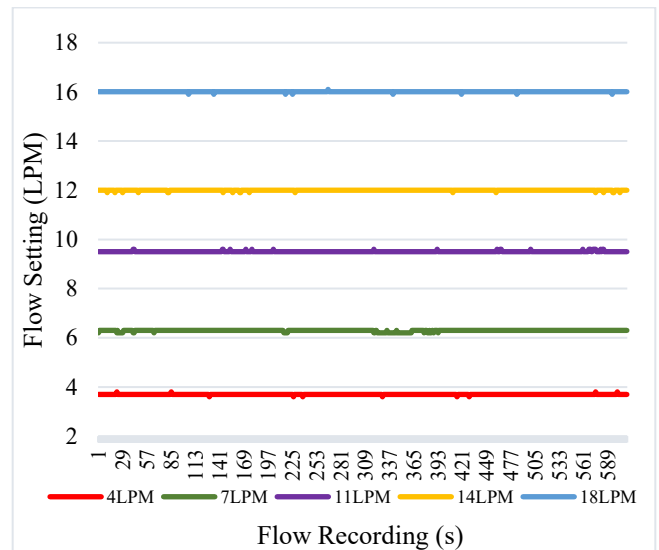


FIGURE 8 Graph of constant flow readings

FIGURE 8 depicts a graph obtained from the second method of data acquisition. By utilizing a flow meter, this sensor was tested for its ability to measure constant flow values, thereby assessing its stability. In this method, the flow meter was set at 4, 7, 11, 14, and 18 LPM, and readings were recorded for 60 seconds at each setting. The graph illustrates that the sensor demonstrates excellent stability in measuring constant flow values, with only minor fluctuations of approximately ± 0.1 LPM observed. These findings indicate that the sensor exhibits high sensitivity, capable of detecting changes as small as 0.1 LPM. The variations in flow readings on the graph may be

attributed to the positioning of the hoses, which were suspended and subject to movement during the data acquisition process. Additionally, these variations could also be influenced by the fluctuating flow capacity of the anesthesia machine.

IV. Discussion

The results of the data collection in the research study have provided valuable insights into the accuracy and stability of the developed flow analyzer module. The error values obtained from comparing the module's readings with a standard gas flow analyzer are crucial benchmarks for determining the accuracy of the sensor. The study found that the largest error values for the flow analyzer module were 3.49% for PIF, 2.99% for PEF, and 5.87% for tidal volume readings. Additionally, when collecting data from an anesthesia machine, the module exhibited a change in flow values of ± 0.1 LPM, which serves as a benchmark for assessing the stability of the sensor.

Comparing these results with a similar study conducted in 2021 that focused on parameters like tidal volume, peak inspiratory pressure (PIP), and oxygen concentration reveals differences in error values. The previous study achieved lower error values of 1.52% for tidal volume, 1.13% for PIP, and 0.79% for oxygen concentration [26]. The disparities in error values could be attributed to the use of different sensors—GFS131 flow sensor in the prior study versus the AFM3000 flow sensor in the current study.

The module developed in this study primarily focuses on reading flow values in LPM and volume values in mL. It targets parameters such as PIF, PEF, inspiratory tidal volume (VTi), and expiratory tidal volume (VTe). The study's limitations include the absence of additional sensors such as pressure sensors or oxygen concentration sensors, which would have expanded the parameters that the module can measure. Moreover, the module lacks data storage capabilities, necessitating manual entry of information into a worksheet.

Ventilators are critical life-support devices that require periodic calibration to ensure proper functioning. The developed module aims to simplify the process of testing ventilator performance, potentially improving the quality of healthcare services in hospitals. However, there are some limitations to this research that should be acknowledged and addressed:

1. Limited Parameters: The module developed in this study focuses solely on flow and volume parameters. Integrating additional sensors to measure pressure, oxygen concentration, and other relevant parameters could enhance the module's functionality.
2. Manual Data Entry: Lack of storage capabilities in the module requires manual data entry, potentially leading to errors or inefficiencies. Exploring options for automated data storage and retrieval would be beneficial.

3. Sensor Comparison: Since sensor choice can impact error values, future research could involve comparing the performance of different sensors under similar conditions to identify the most suitable sensor for accurate measurements.
4. Wider Range of Patients: The study could potentially benefit from a broader range of patient scenarios and conditions, which could provide a more comprehensive understanding of the module's performance across various clinical settings.
5. Further Cost-Effectiveness: While the module aims to enhance ventilator testing, considering cost-effectiveness and affordability is crucial, especially in healthcare environments with budget constraints.

Addressing these limitations and building upon the findings of this study could lead to the development of even more advanced and accurate flow analyzer modules, ultimately contributing to improved patient care and ventilator maintenance practices in medical facilities.

V. Conclusion

The purpose of my research is to test the performance of the AFM3000 sensor in terms of stability and accuracy in reading flow. That way this research can provide information on the suitability of the AFM3000 flow sensor on a gas flow analyzer. The biggest error value of this module is 3.49% for the PIF parameter, 2.99% for the PEF parameter, and 5.87% for the tidal volume parameter. In reading the constant flow rate value with the anesthesia machine, the results of changes in flow that are read are ± 0.1 LPM. It is hoped that the research that I have made can be used as a reference for further research and can be used to conduct ventilator testing.

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