Design and Development of Miniature Turbine Based Flow Sensing Device for Respiratory Flow Diagnosis

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Abstract: ***Pulmonary diseases form an important part of the national burden of diseases. Respiratory flow testing is integral to management of pulmonary diseases. The paper presents exploratory study and design of a flow sensing device that is used to diagnose the respiratory flow. It is helpful in reliable and fast screening of respiratory diseases, so that appropriate action can be taken to cure the diseases. The system is designed in a modular way and consists of: mouthpiece, interfacing hardware and software unit. A spirometer is a medical instrument designed to measure the flow of air inspired or expired by human lungs. The device is designed to perform a spirometry test which provides us with two important parameters: Forced Vital Capacity (FVC) and Forced Expiratory Volume in the first second (FEV1). These parameters are helpful in determining the results. Primary focus is not to identify the type of respiratory disease but to calculate the parameters FVC, FEV1 and their ratio so that a comparative analysis can be done based on the different readings of the same test object for each individual. For a normal person the ratio FEV1/FVC is 75% or more. The device consists of a mouthpiece, inside which a miniature turbine is fixed. Hall sensor sense the rotations of turbine and & gives the output voltage proportional to the magnetic field strength, which is proportional to rotations of turbine. The purpose of the AT89s52 is to convert the rotations of turbine to a particular volume by as per the input air flow. Flow rate is calculated and can be used by physicist to diagnose the patient.***

Keywords: FVC→Forced Vital Capacity, FEV1→Forced Expiratory Volume in the first second of FVC , FER→Forced Expiratory Ratio, FSD→Flow sensing Device, PC→Personal Computer

1. Introduction

The harmful health effects of breathing contaminated air can cause numerous respiratory diseases. Today, due to increase in pollution and habits like smoking, alcohol use etc is giving a day by day increase to various breathing problems. Breathing difficulties may also be due to the problems with any of the respiratory organ or any other health problems. Thus for accurate medical diagnosis, an FSD is needed, which is capable of performing fast and reliable screening of such diseases. Spirometer is one such device that is used to measure the flow of air inspired or expired by human lungs. Spirometry test provides many parameters, but two important ones are helpful in determining results. These are:

- FVC
- FEV1
- FEV1/FVC ,also known as FER

FVC is defined as the maximal volume of air expired with maximally forced exertion from a point of maximal inhalation.
FEV1 is defined as the volume of air exhaled in the first second of FVC.
FER represents the percent of the lung size (FVC) that can be expired in one second.

There are many such systems available in the markets today. Previously there is no such a device that is using the technology of miniaturized turbine with implementation of Hall Effect sensor to measure the volumetric flow of air inhaled or exhaled by lungs.

2. Related Works

As lot of research work is going in the field of development of flow sensing devices that can be used to diagnose the respiratory flow diseases. In this paper, a low-cost mobile spirometer known as TeleSpiro has been proposed which is used in resource limited settings. Spirometer employed two pressure sensors: Differential pressure sensor, Dual humidity/pressure sensor. Microcontroller and USB hardware were are also mounted on the PCB for measuring air flow in the custom device having respiratory air flow tube. Programming of the designed embedded circuit is done in a way so that it can transmit the data to computer/smart phone. Software code written can filter and take out respiratory cycles from digitized data. The intended device satisfied the rigorous design criteria of resource-limited settings and make considerable inroads in giving the evidence-based chronic respiratory illness management. The differential pressure signals from TeleSpiro showed robust, reproducible response to the delivery of physiologic lung volumes. The paper gives the conclusion that the designed machine satisfied the rigorous design criteria of resource-limited settings and criteria of ERS/ATS. [1]

The designed spirometer employs thermistor based sensor. The respiration rate is measured by calculating FVC, FEV1.The designed sensor consists of thermistor of 1k: glass type and bead type each. Comparison is done among these two thermistors and LM35 is used as sensor.After signal conditioning, spirometry parameters FVC, FEV1 are calculated. These parameters are useful for how quickly occupied lungs can be emptied. The respiratory sensor designed is used in the range of 1K, 10K, 100Ω.The experimental results collected from the subject are promising.In this paper, a new scheme of is put forward. [2]

The working principles of major test techniques and instruments including spirometry, peak flowmetry, body plethysmography, nitrogen washout, and ergospirometry are described. The measuring range for an adult is from 25 ml/s to 10l/s. The typical flow volume loops are discussed for normal, obstructive, restrictive, emphysema, stenosis conditions. Cooperation-free methods have been developed, which is a latest advancement in the field of PFT. Different procedures are developed and parameters in advanced pulmonary function testing are derived from main parameters. [3]

This paper presents quality of Spirometry Testing. Shorter expiratory time creates less stress on the patient. Normally it takes 6s or less to fully empty the lungs.Usually, theFEV1/FVC is 70-75%, or more. Lower ratios indicate an obstructive ventilatory disorder. A high ratio (i.e., >85%) indicates very rapid lung emptying of a small vital capacity and is indicative of a restrictive ventilatory defect. The paper describes the quality control issues. The calibration of all spirometers should be tested using a 3-L syringe. Algorithm for the interpretation of spirometry results is developed based on the values of FVC, FEV1, and FEV1/FVC. Based on this algorithm presence of various obstructive and restrictive ventilatory defects such as Asthma, COPD is sensed. [4]

Equipment can be used as a spirometer if it meets the American Thoracic Society (ATS) standards. According to ATS the flow range for FVC and FEV1 is 0-14 L/s.FVC time should not exceed more than 15 seconds.Detail perspective of procedure and instructions involved is taken as standard. It includes pre-test instructions, instructions to be followed during the test and procedure to record the results. Calibration of spirometer is done as a part of quality control. The devices involved in the measurement of flow-volume are calibrated with 3L spirometry syringe. The Equipment Maintenance/Repairs, Cleaning/Sterilization etc. are covered in the closing section of the handbook. [5]

3. Basic Principle

The basic principle of working of Turbine based FSD is the principle of Hall Effect. According to the principle of Hall Effect whenever a current carrying conductor is placed in a varying magnetic field, a voltage is generated perpendicular to both current and magnetic field and this voltage is proportional to the magnetic field strength.

When the input air strikes the turbine, it starts rotating in a clockwise direction. These rotations will cause the magnets mounted on the turbine to induce a magnetic field surrounding them. When this magnetic field is sensed by Hall Effect sensor, then it will produce an output voltage in the form of pulses. The number of output pulses produced by sensor is proportional to the varying magnetic field produced by the magnets, which is in turn proportional to the rotations of the turbine.

In the present work head on approach of Hall Effect sensor has been used.

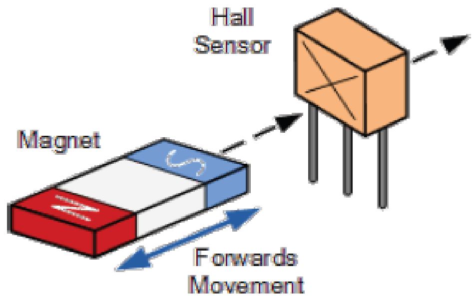

Figure 1: Head on detection in Hall sensor

The output voltage is a function of distance of South Pole of the magnet from the active face of the sensor. When the magnet is just below the hall sensor, magnetic field strength is strongest and output will be a high (1), but when the magnet is moved away from the sensor, magnetic field strength decreases and output will fall to low (0). In the proposed work, Hall Effect sensor WSH130 has been used because it is a digital output sensor and its output has only two states, "ON" and "OFF".

4. Block diagram

The block diagram of Turbine based Flow sensing Device (FSD) is shown in Figure 4.1as shown below. It consists of Mouthpiece, Turbine, Hall Sensor, Microcontroller AT89S52, LCD display, Power Supply Unit, Buzzer, Keypad, MAX232, RS232 and PC. The power supply unit consists of two Capacitors, one Voltage Regulator and a Battery. Miniature turbine is mounted inside the mouthpiece. Two neodymium magnets are fixed at equal distance from each other on the rotor of the turbine. The Hall Effect sensor is positioned parallel above the turbine. The block diagram explains the simple working of the system.

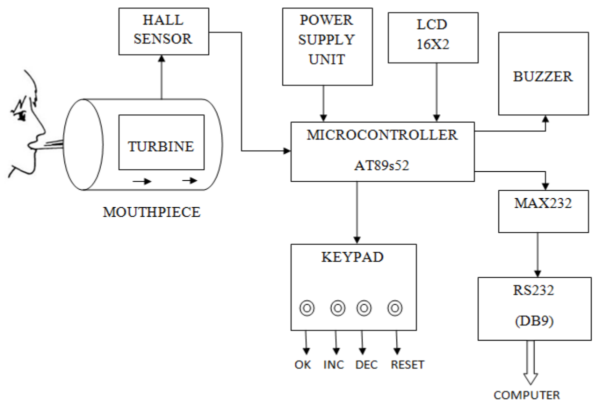

Figure 2: Block Diagram

The heart of the system is an AT89S52 microcontroller. The controller runs the software to control the entire system. +5V regulated power supply is given to the microcontroller, Hall Sensor module and other parts of the designed system. When the test starts patient blows with maximal exertion inside the mouthpiece, the turbine will rotate in proportion with the input flow. These rotations will cause the magnets to induce varying magnetic field surrounding them. When this varying magnetic field is sensed by Hall Effect sensor, then it will produce an output voltage in the form of pulses.LED will turn on according to the pulse count i.e. if the pulse count is 50 then LED will turn on 50 times.

BC547 has been used for the purpose of switching the buzzer on/off. The signal from the microcontroller is fed directly to the base of a transistor. It is used to trigger the buzzer which identifies the passing of air inside the mouthpiece, causing the switching on of LED2 and buzzer for a particular time that has been set for the test. This feature alerts the patient that the test has been started, and he/she should try to keep blowing until the buzzer stops. Keypad is designed with four push button switches.LM7805 receives input voltage of 12 V from a Li-ion battery. This alternate is used to make the system portable and less bulky.

The LCD display is used to show different conditional messages and calculated values for parameters FVC, FEV1, FER. The MAX232 circuit is used to level the voltage difference between RS232 and microcontroller. The parameters FVC, FEV1 and FEV1/FVC are calculated and displayed over LCD and PC.

All the operations are synchronized by a software code that is developed for the present system. Software maintains the proper coordination among the different modules and satisfies the conditions which are required for the proper functioning of the Turbine based FSD.

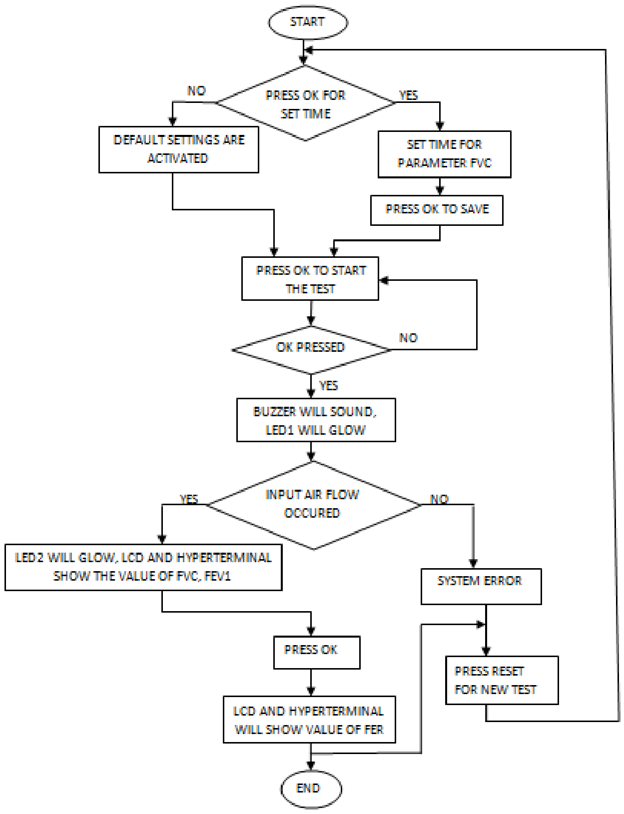

Figure 3: Flow Chart

When the power button is pressed, the system will turn on. Operator is asked to set the time. If within the preset delay time, OK switch is pressed the user comes in manual mode of setting time, else default settings will be activated. Default value for FVC is set as 6 seconds. The values for parameters FVC, FEV1 are displayed over LCD and Hyper Terminal. If the test has started but no input flow has occurred, the display will show system error, and user is advised to press the RESET switch in order to perform the test from the beginning. Now press the OK switch, and value of FER is displayed over LCD and Hyper Terminal. These values can be saved. To take the next test, press the RESET switch and the process will continue as mentioned

5. Mouthpiece and Turbine construction

Mouthpiece is made of white nylon plastic sheet of 6mm thickness. With this nylon sheet a hollow pipe is made. The radius of inlet pipe is smaller than the outlet pipe .This is done so that maximum air can be flown from input to output. If the area of inlet pipe is smaller than the outlet pipe then less force is required to flow the maximum air. Miniature turbine is placed in the middle area of mouthpiece. Turbine is made of black nylon sheet material. Two Neodymium magnets are placed at an equal distance on the rotor of the turbine. Neodymium magnets are permanent magnets and are preferred to use because they exhibits very strong adhesive force, occupies very less space as they are very tiny in size and are very light in weight. Hence they are preferred to use in applications where miniaturization is required.

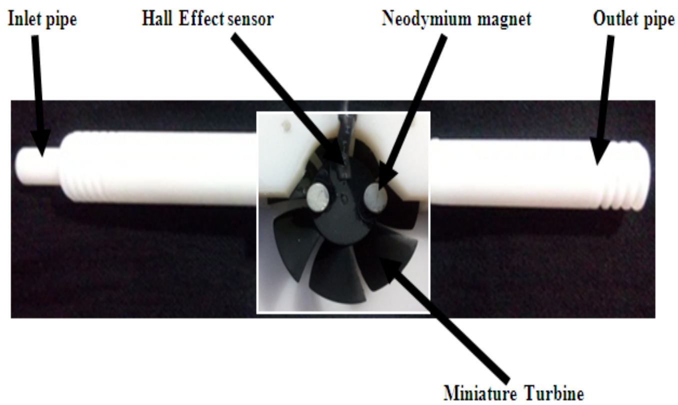

Figure 4: Mouthpiece Internal Structure

Turbine is fixed inside the mouthpiece and the covering of turbine is done with thin sun sheet material made of polycarbonate. Turbine is visible from the top and the cover can be removed when cleaning or some replacement is required.

6. Calibration Process

The quality of any spirometer is closely dependent to its calibration. A check on quality is necessary to rate the accuracy and precision of the device after calibration. When a known volume of air is measured by the spirometer and it is found is approximately same of the known value, then the device is considered accurate. If the same parameter is calculated repetitively and the resulting values are related, then the device is precise. The devices used for both spirometry and flow volume measurements have to be calibrated with a 3L syringe. This calibration is carried out each day the device is used. Present work is based on Turbine based spirometers, which are free from frequent calibration problems. The proposed system implements a Hall Effect Sensor, which senses the rotations of the turbine.

The Hall Effect sensor WSH130 produces an output voltage in the form of pulses. The number of output pulses is proportional to the rotations of the turbine. LED will turn on according to the pulse count i.e. if the pulse count is 50 then LED will turn on 50 times. The units of a spirometer are in liters or milliliters. Hence the system needs to be calibrated in the same units that are used in spirometer. For precision and accuracy purpose this pulse count is calibrated in terms of milliliters.

The calibration a flow sensing device can be done with a standard spirometer. A reference spirometric device known as RMS Med-Spiro is taken. Constant and similar air flow is fed to both the Turbine based FSD and RMS Med-Spiro simultaneously. Time is kept constant. Different v readings are taken, values are approximated and a calibration graph is plotted. Reference value to be set in Turbine based FSD is calculated by using standard formulas of mathematics and used to develop the software code for the air flow measurements. Now Turbine based FSD gives the output in milliliters.

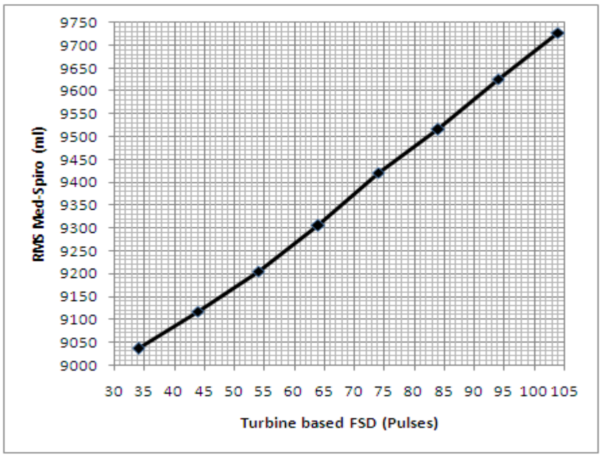

Figure 5: Calibration graph

7. Results

The objectives of present work have been achieved and an efficient system is developed which consists miniaturized turbine with implementation of Hall Effect sensor to measure the volumetric flow of air inhaled or exhaled by lungs. Main goal of the system was to develop a Turbine based FSD that can measure the air flow and display it on LCD, Hyper Terminal according to the input provided by patient and to develop a software code that can calculate the parameters FVC, FEV1, FER as per the input flow.

The device developed is properly working and is ready to use as a spirometer. The designed system is functional and all tests implementing the hardware and software are done. When the system is functional and all tests implementing the hardware and software are done then results are displayed over LCD and Hyper Terminal. At least three tests should be done on a patient and it is acceptable to select the highest FVC, highest FEV1 from different tests, till the maximal effort is obtained from the patient. The results can be analyzed with reference to ATS standards.

Spirometry tests are totally dependent on efforts of the operator and subject. Hence, the patient should fully collaborate with the operator while performing the test. The developed prototype is used to test its functionality and performance. Different readings are taken and parameters are calculated. The details of test are given in Table 7.1

Table 1: Breathing test results:

S.No.	Parameter	Value of the Parameter
1.(a)	FVC (ml)	11810
1.(b)	FEV1 (ml)	9160
1.(c)	FER (%)	77
2.(a)	FVC (ml)	9980
2.(b)	FEV1 (ml)	8250
2.(c)	FER (%)	82
3.(a)	FVC (ml)	9840
3.(b)	FEV1 (ml)	8660
3.(c)	FER (%)	88

From the above values physicist can analyze the results of the tests. Normally, the value for FEV1/FVC is 75%, or more. Lower value for this ratio indicates an obstructive defect in the lungs. A high value for this ratio (i.e. >85%) depicts very fast lung emptying and is indicative of a restrictive defect.

The system is designed to meet the ATS standards. According to ATS the acceptable flow range for FVC, FEV1 should be 0-14 L/s and FVC time should not exceed more than 15 seconds. In order to obtain the maximal values for FVC and FEV1, operator should make sure that the patient initially inhales to his/her Total Lung capacity (TLC), and then exhale with maximal effort.

8. Conclusion

The demand for accurate diagnosis of breathing problems is at high pace, because of increased contaminations in the atmosphere and rise in habits like smoking, alcohol use etc. Proposed system is a solution to these problems. It can be used as an application in spirometry and flow –volume measurements. It provides effective measure of PFT parameters such as FVC, FEV1 and FEV1/FVC. It provides highly reliable and time efficient way to measure the PFT parameters. The proposed system is especially appropriate for its clinical use. The proposed system is simple and easy to operate and install. It incorporates simple hardware by using small number of components. The system is portable, small in size, consumes less power and is of low cost. It implements fast and reliable technology, for efficient diagnosis of any respiratory illness.

9. Future Scope

Although the designed system is very efficient, but there is always a room for improvements. Graphic LCD can be embedded in the system so that real time values of parameters can be plotted. Moreover system can make use of EEPROM which can hold the multiple records of various patients. Android application or window based application software can be designed for the proposed system, which will show real time interfacing of the device. The present system is powered from a battery. The use of battery can be eliminated by designing the system in such a way so that it can receive power directly from the computer.

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