

DESIGN, ANALYSIS AND IMPLEMENTATION OF SPIROMETER

Asmita Parve Mokal¹, Dr. M.J. Sheikh², Bipin D. Mokal³

¹M Tech Student, Department of Mechanical Engg, B.D.C.O.E., Sevagram – 442102

²Prof and HOD, Department of Mechanical Engg, B.D.C.O.E., Sevagram – 442102

³Head of Division, Biomedical Engg, DMIMS (DU), Wardha - 442001

Abstract - Spirometry is a type of pulmonary function test that measures the amount of air volume and the speed of air flow from a patient's breath in order to assess lung function. The goal of this project is to develop and validate a mobile spirometer technology based on sensing assembly. Pulmonary diseases are major causes of ill-health throughout the world. Pulmonary infection such as acute bronchitis and pneumonia are common. The diagnosis of these diseases is facilitated by pulmonary parameter analysis using spirometer which has many limitations such that analog or mechanical devices does not have that accuracy and provision to store the data for further investigation. In electronic spirometer we cannot get inspiratory parameters. The measurement of flow and volume in the breathing cycle can be done by fan transducers. Breathing tests are designed to identify and quantify defects and abnormalities in the function of respiratory system. These tests can be broadly classified into two types, depending on the lung characteristics that they measure. These are gas exchange functions and dynamic lung functions. The dynamic lung functions test the Forced Vital Capacity (FVC), Flow-Volume Curves, time-volume curves, Maximum Voluntary Ventilation (MVV) and airway resistance. The dynamic lung function test is the most common test and highly informative and useful in most of the cases.

Key Words: Pulmonary, Spirometer, Transducer, and Aerodynamic

1. INTRODUCTION

In Greek 'Spiro' means 'breathing' and 'Metry' means measurement. Spirometry is the term coined to the basic lung function tests that measure the air that is expired and inspired. There are three basic related measurements: volume, time and flow. Spirometry is objective, noninvasive, sensitive to early change and reproducible. With the availability of portable meters it can be performed almost anywhere and, with the right training, it can be performed by anybody. It is performed to detect the presence or absence of lung disease, quantify lung impairment, monitor the effects of occupational/environmental exposures and determine the effects of medications. [2]

Spirometry is a standard test doctors use to measure how well your lungs are functioning. The test works by measuring airflow into and out of your lungs.

To take a spirometry test, sit and breathe into a small machine called a spirometer. This medical device records the amount of air you breathe in and out and the speed of your breath. [3]

1.1 Conditions That Can Be Picked Up and Monitored Using Spirometry

Normal ventilation of the lungs is affected by many types of obstructive and restrictive pulmonary diseases:

1. Obstructive Diseases (obstructions of the trachea, bronchi, and bronchioles). Common causes:
 - a. Asthma
 - b. Bronchitis
 - c. Bronchiectasis
 - d. Chronic obstructive pulmonary disease (COPD)
2. Restrictive Diseases (inability to expand the lungs).

Intrinsic Causes:

- a. Destruction of the lung tissues (parenchyma)

Extrinsic Causes:

- b. Problems with the tissue layers lining the lungs (pleurae)
- c. Extra-pulmonary problems [4]

1.2 Type of Spirometer

There are two different technologies used to make spirometers.

- Incentive or Therapeutic spirometer
- Volume type
- Flow type
- Diagnostic spirometer[5]

1.3 Respiratory Parameter

- Total Lung Capacity = Inspiratory Reserve Volume (IRV) + Tidal Volume (TV) + Expiratory Reserve Volume (ERV) + Residual Volume (RV)
- Vital Capacity = Inspiratory Reserve Volume (IRV) + Tidal Volume (TV) + Expiratory Reserve Volume (ERV)
- Inspiratory Capacity = Inspiratory Reserve Volume (IRV) + Tidal Volume (TV)

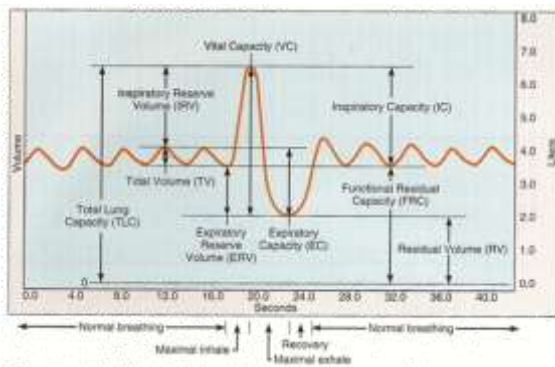


Fig -1: Typical Spirogram

- Functional Residual Capacity = Expiratory Reserve Volume (ERV) + Residual Volume (RV) [7]

2. PROTOTYPE CONSTRUCTION

As we are using readymade fan as a heart of a sensor we have to overcome its drawbacks. Firstly it has central flat surface causing huge resistance to the air exhaled and inhaled too. Second hurdle is fan supports which are also flat. Third hurdle is wires running through the air pathway blocking pathway. To overcome all these issues aerodynamic design is constructed in prototype. First designed in Solid Works software and then taken 3D printout of the same

3. DETAIL DESIGN

Total designing includes creating minimal resistant air pathway in both directions inhalation and exhalation. Detail design is as shown in Fig.2

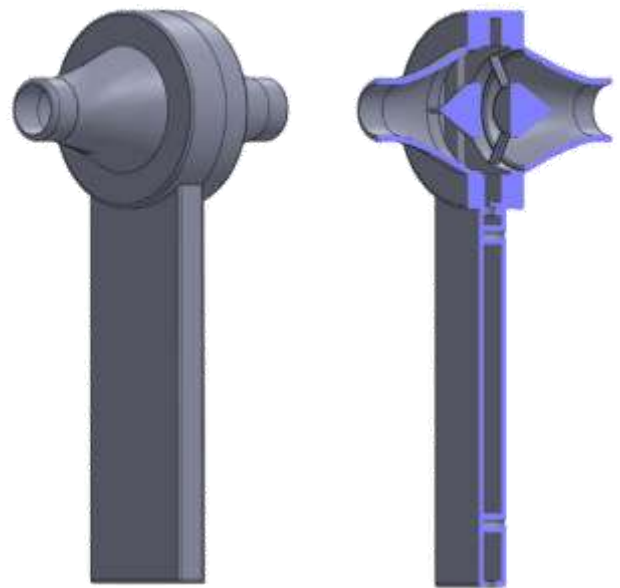


Fig -2: Final Assembly Solid Works Drawing

4. CALIBRATION OF SPIROMETER

The results shown below are of calibrating the developed spirometer by using the calibrator. Calibrator is providing air flow of 1 lit/s at 5V and 2.1 lit/s at 6V the other readings are calculated for the range 4.25V to 10.75V as maximum voltage displayed on display is 11V and calibrator fan will stop at 4 V. Table 6.1 shows the calibration table. Any spirometer can be calibrated according to this table by simple stapes such as set voltage on calibrator, attach the spirometer mouthpiece to the outlet of calibrator and adjust the spirometer reading according to the Table -1

Table -1: Calibration of developed transducer

Standard Calibration			Inspiration Calibration			Expiration Calibration				
Sr. No.	Voltage (V)	Rate of flow (l/s)	Sr. No.	Voltage (V)	Rate of flow (ml/s)	Sr. No.	Voltage (V)	Rate of flow (l/s)		
1	4.25	0.18	1	10.75	7306	7.31	1	10.75	7226	7.23
2	4.5	0.45	2	10.5	7017	7.02	2	10.5	7014	7.01
3	4.75	0.73	3	10.25	6732	6.73	3	10.25	6700	6.7
4	5	1	4	10	6478	6.48	4	10	6505	6.51
5	5.25	1.28	5	9.75	6210	6.21	5	9.75	6230	6.23
6	5.5	1.55	6	9.5	5948	5.95	6	9.5	5994	5.95
7	5.75	1.82	7	9.25	5677	5.68	7	9.25	5653	5.65
8	6	2.1	8	9	5441	5.44	8	9	5426	5.43
9	6.25	2.37	9	8.75	5153	5.15	9	8.75	5164	5.16
10	6.5	2.65	10	8.5	4850	4.85	10	8.5	4854	4.85
11	6.75	2.92	11	8.25	4570	4.57	11	8.25	4594	4.59
12	7	3.2	12	8	4283	4.28	12	8	4341	4.34
13	7.25	3.47	13	7.75	3989	3.99	13	7.75	4075	4.08
14	7.5	3.75	14	7.5	3694	3.69	14	7.5	3739	3.74
15	7.75	4.02	15	7.25	3411	3.41	15	7.25	3474	3.47
16	8	4.3	16	7	3137	3.14	16	7	3172	3.17
17	8.25	4.57	17	6.75	2878	2.88	17	6.75	2888	2.89
18	8.5	4.85	18	6.5	2593	2.59	18	6.5	2633	2.63
19	8.75	5.12	19	6.25	2309	2.31	19	6.25	2337	2.34
20	9	5.4	20	6	2071	2.07	20	6	2112	2.11
21	9.25	5.67	21	5.75	1801	1.8	21	5.75	1795	1.8
22	9.5	5.95	22	5.49	1511	1.51	22	5.5	1523	1.52
23	9.75	6.22	23	5.25	1249	1.25	23	5.25	1225	1.23
24	10	6.5	24	4.99	922	0.92	24	4.99	941	0.94
25	10.25	6.77	25	4.73	656	0.66	25	4.75	652	0.65
26	10.5	7.05	26	4.51	342	0.34	26	4.5	349	0.35
27	10.75	7.31	27	4.24	67	0.07	27	4.25	79	0.08

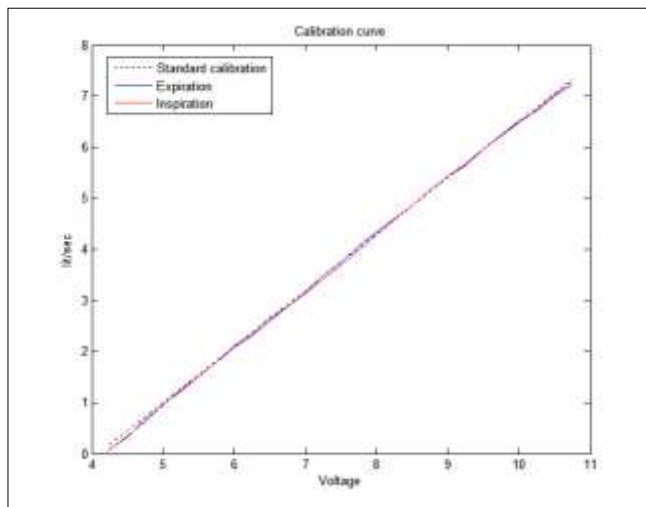


Fig -3: Calibration graph of developed transducer

The developed spirometer is attached to the expiratory end of calibrator and various recordings are taken by decreasing voltage in the interval of 0.25V. Total rate of flow is calculated by using MATLAB program and graph is plotted. Calibration graphs are shown in Fig. 3.

5. SIGNAL CONDITIONING THROUGH MATLAB

As subject is blowing into the sensor or sucking through sensor, air is passed through fan blades causing rotations in fan blades which gives variable analog signal. This analog signal is recorded through MATLAB as a raw signal. This raw signal is shown in Fig 5(1).

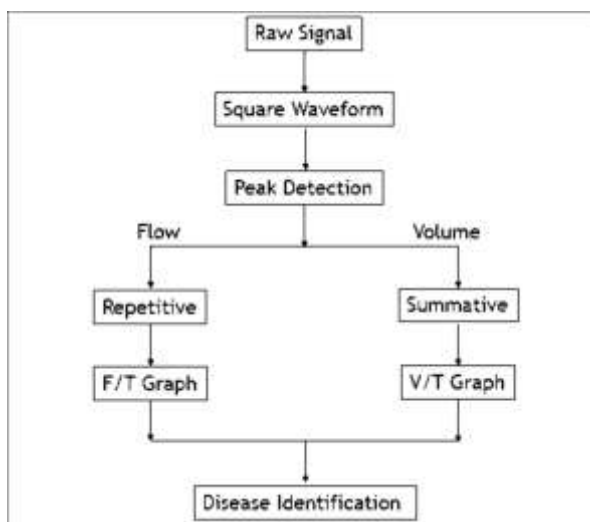


Fig -4: Block Diagram Of Signal Conditioning

As we have converted this raw signal to square wave. The square wave is shown in Fig 5 (2).

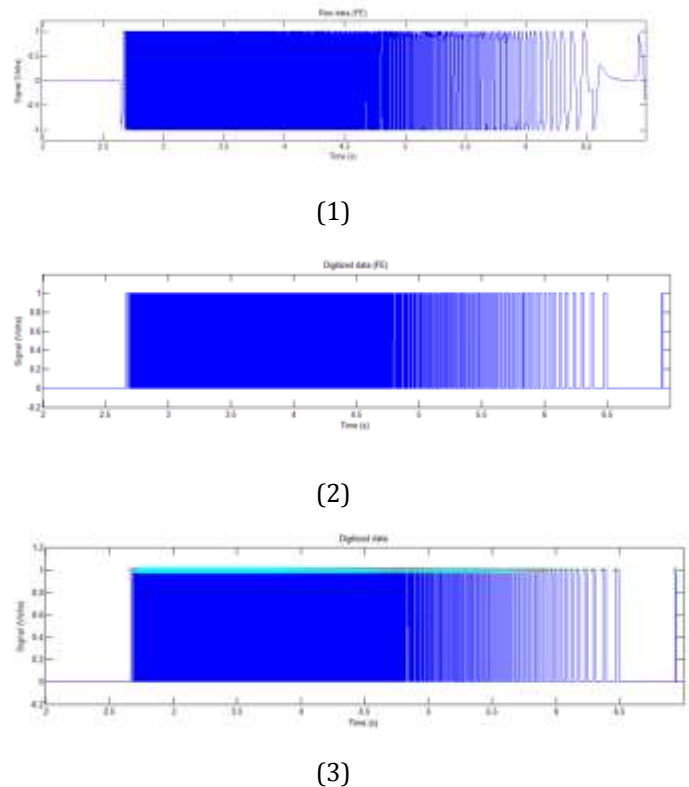


Fig -5: (1) Raw signal generated by transducer (2) Digitalize data (3) Peaks found

We have detected rising peak and falling peak of the square wave as shown in Fig 5 (3).

6. EXPERIMENTATION WITH DESIGNED SPIROMETER

6.1 Experimentation

Entire data collection flow chart is shown below in Fig 6. Once both waveforms are recorded we can save the data by clicking save button in graphical user interface of MATLAB. After this report can be generated just by pressing report button. Once we press Report button GUI will ask for inputting data through get data button. This report will give all pulmonary function parameters and also analyses the data and predict whether the subject is normal or abnormal.

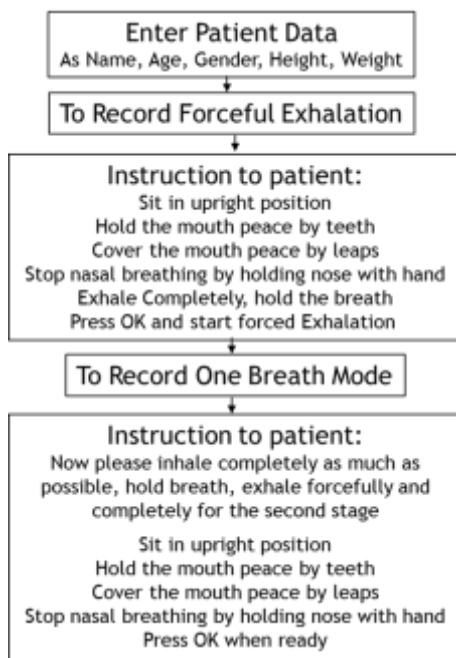


Fig -6: Block diagram of software data collection

6.2 Spirometry procedure – subject preparation

Subject preparation: Before performing any pulmonary recording procedure following precautions to be taken

- Subject should wear comfortable, loose clothing,
- He should avoid eating substantial meal before two hours of test;
- He should avoid vigorous exercise before 30 minutes of testing.
- He should sit in upright posture during procedure, there should not be any air leakage from sides of mouth piece,
- Subject should be given a brief training about Spirometry procedure so that the false readings can be avoided, and
- Nose clip should be used.

6.3 Common Patient Related Problems When Performing FEV Maneuver

FEV maneuver is completely dependent on the subject if subject understand the procedure properly then he can give proper results in Spirometry. Some problems in FEV maneuver are as:

- Slow start,
- Submaximal effort,
- Cough and
- Extra breath

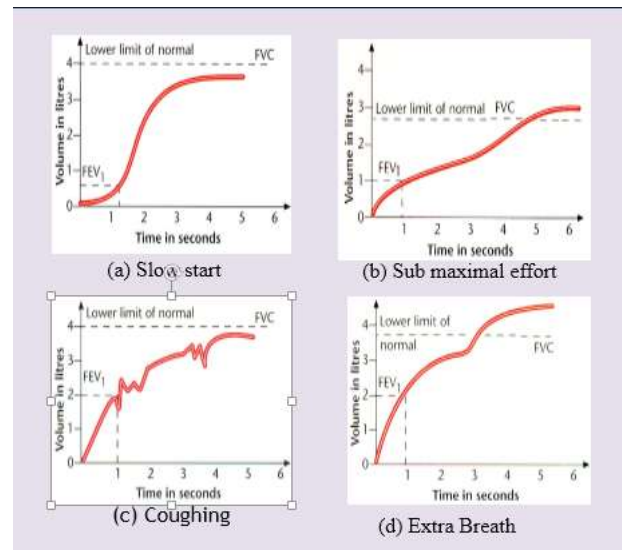


Fig -7: Problems in FEV Maneuver

For normal person, the curve is smooth it does not have any irregularity, no upward curve is observed and it reaches to the plateau. FVC is read at the top of curve, where it reaches to the plateau. In slow start condition as shown in Fig. 7 (a), patient has not made a maximum effort from the start of the blow. Trace will not be observed smooth and upward. This affects the ratio FEV1/FVC and false readings are obtained as FEV1 will be very less than the predicted value but the subject may be normal. In submaximal effort condition also similar condition occurs but flow increases gradually as shown in Fig. 7 (b). This will also affect all ratios. As indicated in Fig. 7 (c) the cough can cause irregularity in FVC curve. In extra breath condition FVC is affected as shown in Fig. 7 (d). Hence accordingly the patient must be instructed to start blow with maximum effort and as forcefully as he can so that the readings can be proper.

7. RESULT AND DISCUSSION

Fig 8 shows GUI front panel generated by using MATLAB. Fig. 9 is automatic generated report of the subject indicating all observations, normal values and primary diagnosis from spirometry.

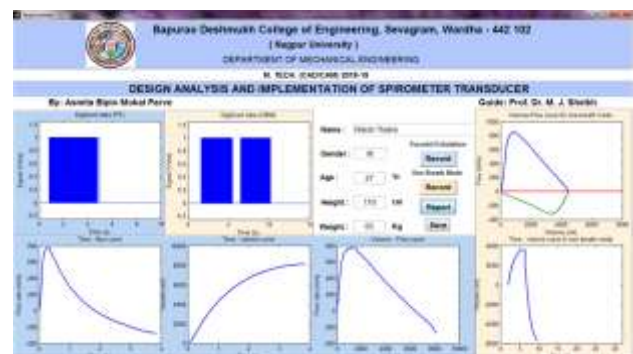


Fig -8: Front panel of spirometer software

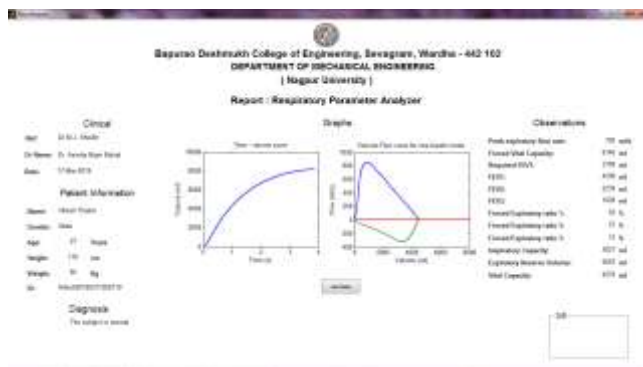


Fig -9: Report generated by spirometer software

Table -2: Spirometry readings

Sub	Age	Sex	Height	Weight	PFER	FVC	FEV1	FEV2	FEV3	FEV1/FVC	FEV2/FVC	FEV3/FVC
Sub1	24	M	165	62.5	402.46	4482.37	2422.3	2408.4	1105.21	54.07	54.29	25.40
Sub2	24	M	165	62.5	402.46	4482.37	2422.3	2408.4	1105.21	54.07	54.29	25.40
Sub3	22	F	164	59.4	326.1	3424.84	1444.2	2411.86	625.31	42.41	70.38	22.80
Sub4	40	F	174	74	292.21	2744.74	1260	2048.89	659.31	42.84	74.88	24.00
Sub5	48	M	165	62.5	382.72	3211.84	2084.92	2264.99	871.22	54.29	68.26	26.31
Sub6	22	M	165	62.5	402.46	4482.37	2422.3	2408.4	1105.21	54.07	54.29	25.40
Sub7	22	F	164	59.4	326.1	3424.84	1444.2	2411.86	625.31	42.41	70.38	22.80
Sub8	22	M	165	62.5	402.46	4482.37	2422.3	2408.4	1105.21	54.07	54.29	25.40
Sub9	22	M	165	62.5	402.46	4482.37	2422.3	2408.4	1105.21	54.07	54.29	25.40

By using the designed spirometer PFER, FEV1, FEV2, FEV3 and the ratios FEV1/FVC, FEV2/FVC, FEV3/FVC were calculated from nine subjects (6 Male: average weight 66.5Kg, average height 169.8cm in the age group from 22 yr to 48 yr; 3 Female: average weight 64.66 Kg, average height 164.66 cm in the age group from 22 yr to 42 yr;) and tabulated in Table-2.

8. CONCLUSION

New designed spirometer is user friendly. Patient training is easier as patient comfort increase with new design. This unique design gives inspiratory and expiratory parameters including flow and volume calculations. With the advanced design accuracy of the spirometer increases and marginal cost reduction is achieved. Expiration and inspiration parameters can be measured easily by using fan type transducer. This can calculate all lung capacities and volumes including inspiratory vital volume capacity (IVC), Peak expiratory flow (PEF), Maximum voluntary ventilation (MVV) etc.

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