

Peak Inspiratory and Expiratory Flow Meter

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Abstract

A device for measuring both peak inspiratory and expiratory air flows in a single device is desired. Currently, it is common to monitor and diagnose asthma by periodically measuring peak expiratory flow. Vocal chord dysfunction is a relatively new disease, often misdiagnosed as asthma but cannot be cured by asthma treatments. To monitor and diagnose for vocal chord dysfunction, peak inspiratory flows are measured. The final design must be cheap, lightweight, and easy to carry around. Three design ideas are presented but only one will be pursued. Future work entails additional research, building a prototype, and testing it.

Problem Statement

The proposed project is to create a peak inspiratory and expiratory flow meter as a single device. Peak expiratory flow meters are used to monitor asthma and measure flows of about 700 liter per minute. Doctors sometimes misdiagnose vocal chord dysfunction, narrowing of the airways at the vocal chords during inspiration, as asthma. Peak inspiratory meters are used to monitor and diagnose vocal chord dysfunction. Having a peak inspiratory and expiratory flow meter in one device can help prevent a misdiagnosis of a patient's condition. Our device will measure the peak flow at which a person can inhale and exhale air.

Background

Asthma occurs in the lower airways, from the trachea down to the alveoli (air sacs). Asthma is an expiratory problem, caused by a narrowing of the airways and an increase of airway resistance. There are three common causes of asthma, pictured in Figure 1. The muscles surrounding the bronchial tubes can tense causing the airways to contract. Another cause is the bronchial tube lining can become inflamed and swollen. The third cause



Fig 1. Common causes of asthma (Green Island Graphics, 2004)

is excess mucus production which fills into the airway leaving on a small opening for air to pass. Asthma typically occurs in episodes, following exposure to triggers, such as exercise, cold, or substances in the air (Frahmingham School, 2005). Asthma is a common condition which is easy to treat and monitor. There are two measures taken to treat asthma, medication for long term effect and medication for quick response. Long term asthma medications, called anti-inflammatory agents reduce the swelling and sensitivity to triggers and are taken daily. Quick response medications, called Bronchodilators act principally to open the airways by relaxing bronchial muscle (American Lung Association, 2005). In order to monitor asthma, doctors prescribe the use of a peak expiratory flow meter.

Vocal cord dysfunction occurs in the upper airway, specifically the larynx. A person with vocal cord dysfunction usually experiences difficulty inhaling. Vocal cord dysfunction occurs when the vocal cords do not open and shut properly during breathing or speech (Allen, 2002). Typically this occurs during exercise or nervousness. Since the symptoms are similar to those of asthma, wheezing, and coughing, vocal cord dysfunction gets misdiagnosed as asthma. Treatment for vocal cord dysfunction is speech therapy. One way for doctors to diagnosis this correctly is to measure peak inspiratory flow.

There are multiple designs of peak expiratory flow meters and only a couple inspiratory flow meters on the market today. Peak expiratory flow meters are designed to help diagnose and monitor asthma. All of the expiratory flow meters are similar in internal design but vary in outward appearance. The internal structure consists of a thin plate or plunger attached to a spring. The plunger pushes up a lightweight plastic

indicator that corresponds to a flow rate in liters per minute. The force exerted by exhaling moves the spring and plate. Along the side of the incremental ruler, are three colored arrows. These arrows correlate to different zones and are specific to the user. If user measures above the green they are in the controlled zone. Below the red zone is the danger zone and a user should seek medical attention. Between these two in the yellow, two peak flow readings in the yellow zone over a 48-hour period tell you that it may be time to call your doctor for an adjustment in your medications (Allergy.com, 2005).

Each of the three peak expiratory flow meters, pictured in Figure 2, has advantages and disadvantages that should be considered for a final design. The far left design is from Personal Best. It comes in a self contained case which makes it easy to carry around and keeps it clean. Its shape is more rectangular which fits better in more bags



Fig. 2 Current flow meters

and purses. The company also made it user friendly by making it dishwasher safe. Air escapes from this design from the top which limits the complexity of air loss in determining the flow rate. The middle design is from ASTech. It is cylindrical in shape. It is by far the heaviest of the designs and is slightly awkward to carry around. The advantage of this is it is more durable and presumably will last longer. The design also has only air holes at the top. The last of the designs is the most portable of the three. It is from a company called Spirometrics. It can fit easily in one's pocket. It is also dishwasher safe, which makes in more sanitary. This disadvantage in this design is that the air can escape from holes on the outer perimeter of the circular airflow way. This complicates the calibration of the flow rate. The other problem of having air

escape on the sides is that the user has more specific instructions on where to hold it. If the user is not paying attention it could affect their reading



The In-Check is an inspiratory flow meter, pictured in Figure 3. It, like the three expiratory flow meters, is portable.

Fig 3. Inspiratory flow meter (Alliance Tech Medical, 2005)

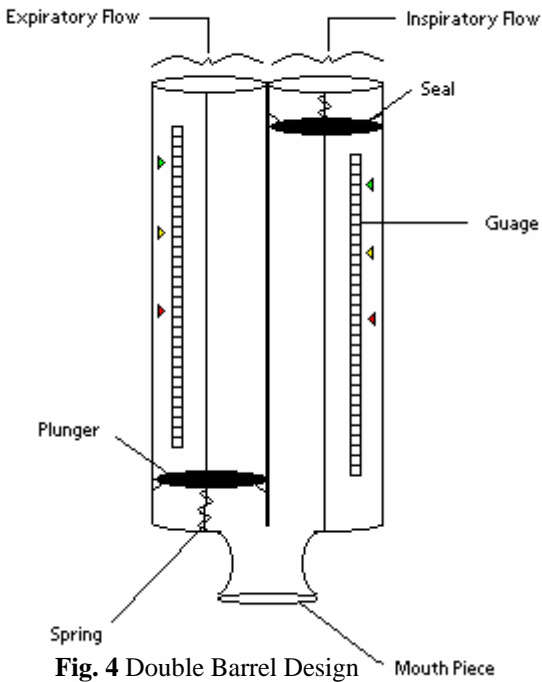
The In-Check is made of plastic and stainless steel. It is easy to clean and durable enough for home use. It also comes with removable mouth pieces. One thing to note about an inspiratory flow meter versus an expiratory flow meter is the plastic. In the inspiratory flow meter it is a clear plastic versus the opaque expiratory flow meters. This is so the user can look inside to see if there are any broken parts that he could possibly be inhaled.

In order to determine the flow rate of the designed peak inspiratory and expiratory flow meter, a few equations will need to be further researched. First, it is known that the force of a spring equals the negative spring constant multiplied by the length the spring stretches. The pressure that is exerted on the plunger of the design is the combined force of the two springs divided by the area of the plunger. There seems to be no simple correlation between the pressure exerted on plunger and the rate of flow. In order to calibrate the design, tests will have to be run upon completion of the device.

Alternative Design 1 (Double Barrel)

The first design includes a device with two side by side barrels that each contains a spring, gauges and a disk. This design is pictured below in Figure 4. This design would combine an expiratory and an inspiratory flow meter into one. The springs would be used to measure the force of air entering the device by the equation $\text{Force} = K(x_1 - x_2)$.

As air enters the expiratory flow barrel, the force of the air will cause the disk attached to the spring to be expelled upward. A gauge that travels with the disk will record the final



flow rate in liters per minute. Similarly, as the force of the air decreases in the inspiratory flow barrel (caused by the operator breathing in), the disk will travel down the barrel and a similar gauge will measure the inspiratory flow rate in liters/minute.

This design includes many advantages and disadvantages. First, this device combines an inspiratory and an expiratory flow meter into one device. In addition, this device is

quite simple involving springs and disks. Disadvantages of this device include a bulky design and two sets of everything can lead to faster failure rate. Furthermore, more parts mean more expense to the manufacturer and the consumer. Finally, the continual use of this device may cause the seals to fail which would lead to inaccurate results. The disadvantages of this design make it clear that this is not the best choice.

Alternative Design 2 (Taser)

Our second alternative design was a drag flow peak detector that measures the flow of air by measuring how much the plate is deflected. This design is shown in Figure 5 below. The device would consist of a plate that is attached to a stress gauge that

measures how much the plate is deflected from the original position. If the plate is deflected in the negative y direction, the digital output would record the inspiratory flow rate. When the plate is deflected in the positive y direction, the stress gauge will measure the expiratory flow rate. This electronic device works by measuring how much stress was placed on the plate by the force from the air. There is a direct correlation between the amount that the plate is deflected and the incoming force of air. The stress gauge then sends a reading to a digital output where the peak inspiratory and expiratory flow is displayed.

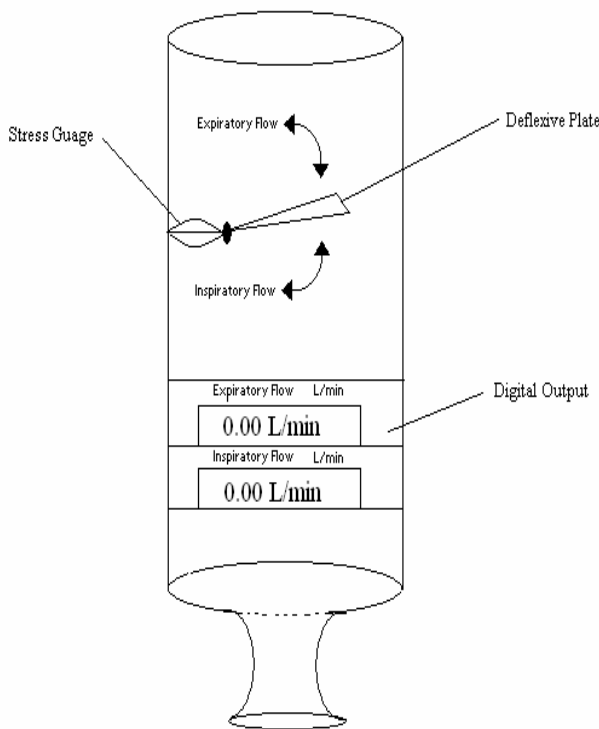


Fig. 5 Taser design with digital displays and a deflection plate with a strain gauge

This alternate design seems like it would be an excellent choice because of the accurate determination of peak flow, compact size, and an easy to read display. When examining this device more closely, the disadvantages of the device make this an unlikely choice for the proposal. The disadvantages include electrical components which make the device expensive, complex and more likely to fail. In addition, this plan must

be used with extreme care to prevent damage to the electronic gauges. Since our client would

like this product to be used by children, the electrical components make it an unsafe and an undesirable product.

Proposed Design 3 (Sniper)

The proposed solution for a flow meter would measure both inspiratory and expiratory flows in one breath. This is ideal because there are no current designs that measure both inspiratory and expiratory flows and would be easier for a patient to use rather than two separate devices. This device would consist of one long tube about 1in. inside diameter. There would be one circular plunger held at rest in the center of the tube by two springs attached to the plunger and the ends of the tube. The plunger and springs

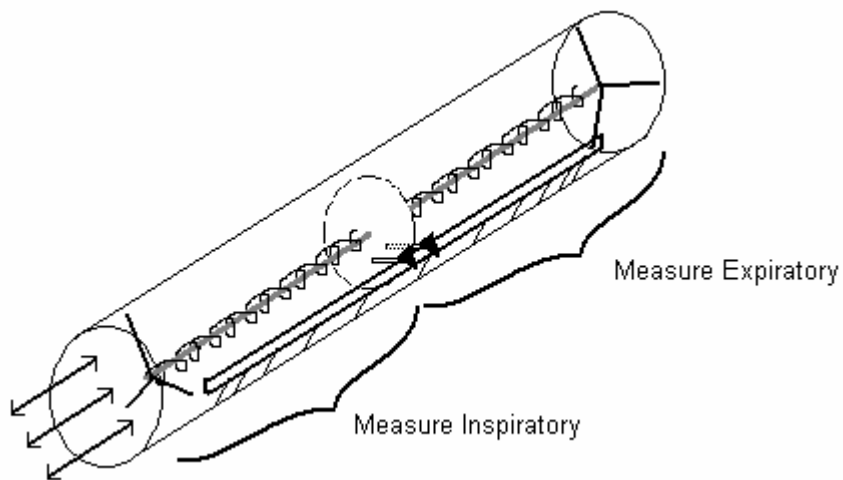


Fig. 6 Proposed Sniper design will measure peak air flow by combining two springs on one plunger.

would move along a thin metal rod down the center of the tube giving support and stability to the mechanism. The force exerted by the springs would be large enough to hold the plunger in the middle but small enough

that when air is moving past the plunger the plunger can move. This proposed design is show below in Figure 6. When exhaling into this flow meter, air would be moving past the plunger causing a slightly higher pressure on the mouthpiece side. This pressure difference would cause the plunger to move farther from the mouthpiece until the force exerted by the pressure balances the force exerted by the springs. When the plunger moves, it would push a small indicator arrow along a scale. This indicator arrow, which slides along a groove in the surface of the flow meter, should have enough friction that it

does not move freely, but loose enough that the plunger can easily push it. This way, the indicator arrow will not move once the plunger has returned to the middle.

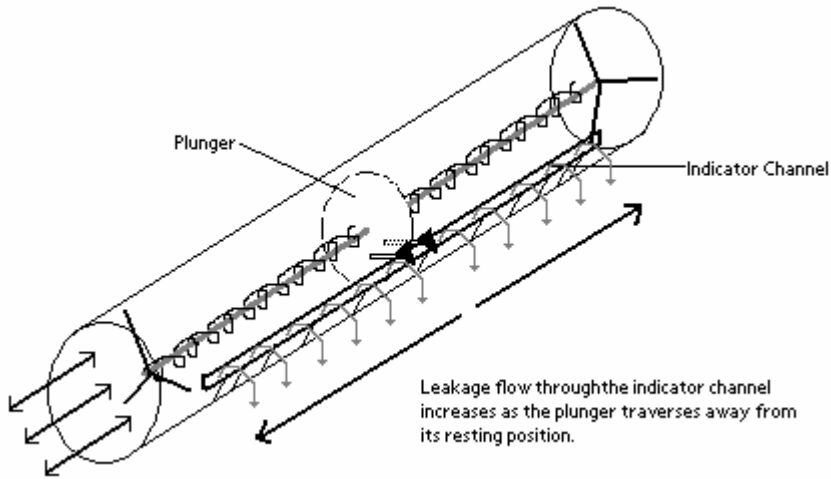
The same principles apply for measuring inspiratory. When air is inhaled, it creates a slight vacuum on the mouthpiece side, so the pressure on the far side of the plunger is higher. Likewise, this pressure will exert a force causing the plunger to move toward the mouthpiece until the forces from the springs cancel the forces due to pressure. The movement of the plunger would push a different arrow toward the mouthpiece side. The distance that the arrow moves, corresponds to the peak inspiratory flow.

This flow meter would ultimately be made of cheap lightweight plastics. Only the springs and rod would be made of metal. The total length of the device should be no longer than eight inches. It would have smooth edges and made of a clear plastic so if something were broken or loose it could be easily spotted.

This design has advantages and disadvantages just like any other design. A key feature in this design is its combined functions. Inspiratory and expiratory flows are measured in the same compartment which reduces space, parts, and therefore cost. Because only one plunger is used and moves two directions, less parts are needed which improves the reliability and life of the product. There are also no electrical parts making it less complicated. The only disadvantage of this design is that because the inspiratory and expiratory scales are in line, the total length of the device will be longer.

A problem with our current design is that the indicator channel is an incision in the tubular enclosure. Because of this, as air flows into or out of the end of the tube there will be some leakage of flow through the indicator channel. In addition the rate at which leakage occurs will not be a linear relationship. As the plunger moves away from the

resting position the area between the incision and the plunger increases, which causes the



leakage flow to increase as the plunger traverses away from the resting position. This is illustrated in Figure 7. This makes it more difficult to make a mathematical model of flow rate, thus making it more difficult to accurately make the indicator calibration markers

the side of the tube.

To overcome this difficulty the device can be calibrated manually using a device that generates a known amount of air flow. By administering a series of flows we can physically measure the how much the plunger traversed by measuring the displacement of the indicator arrow. This data can be used to set up a calibration plot of flow rate vs. distance traversed by the plunger. Performing this for both the expiratory and inspiratory flow rates will allow for an accurate calibration of the device, overcoming the complex mathematical relationship of the leakage flow.

Future Work

The last design that was presented is the design that will be pursued as seen by the design matrix (Figure 8). Much work needs to be done before it is a commonly used item in the medical world. There are still some preliminary calculations that need to be done to determine the strength of the springs. From these calculations, a final schematic with

dimensions can be made and a prototype built. More research into custom molding and the parts used must also be done. Once built, the product must be calibrated as discussed to give the proper measurement readings.

Design Matrix			
1 = Poor & 5 = Excellent			
Design	1. Double Barrel	2. Taser	3. Sniper (Proposed)
Cost	4	1	5
Portability (size, weight)	3	2	4
Reliability	3	3	3
Ease of Manufacturing	4	2	4
Ease of Use	4	5	4
Complexity of Design	3	1	5
Client Preference	3	1	4
Totals	24	15	29

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FIGURES

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Product Design Specifications

September 29, 2005

Inspiratory and expiratory flow meter –Product Design Specifications

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Function: Our client desires a peak inspiratory and peak expiratory flow meter in a single device to monitor for symptoms of asthma and vocal cord dysfunction. It should measure flows up to about 700 liters per second for adults, be cheap, durable, and easy to use with clear measurement readings.

Client requirements:

- . • measure both inspiratory and expiratory peak flow in a single device
- . • cheap to make
- . • Easy to read measurements
- . • Cannot compromise patient or user safety

Design requirements:

1. Physical and operational characteristics

- a. *Performance requirements:* The design must be able to measure inspiratory and expiratory peak flow rates.
- b. *Safety:* The design must not have materials that could be harmful to patient.
- c. *Accuracy and reliability:* This device should measure peak flow rates to about 700 L/min for expiratory and to about 400L/min for inspiratory to within 5 percent.
- d. *Life in service:* The final design will be given to patients who may use them daily for a period of time and then disposed of.
- e. *Shelf life:* The design should last indefinitely.
- f. *Operating environment:* The design must be easily sanitized for normal daily use by a patient.
- g. *Ergonomics:* The design must be portable and easily held up to the mouth in one hand.
- h. *Size:* The design must be small and easily portable. It may be thrown in a gym bag or a pocket.
- i. *Weight:* The design must be light enough to hold up to the mouth and carry around. Should not exceed 2 lbs.
- j. *Materials:* The design should be made primarily of cheap lightweight plastics.
- k. *Aesthetics, appearance, and finish:* The device should look easy to use

with no rough surfaces. Should be easily understandable.

2. Product characteristics:

- a. *Quantity*: One model will be prototyped; if successful, it can be manufactured and used for future use.
- b. *Target product cost*: The cost of the entire device once in manufacturing should be less than \$40.

3. Miscellaneous:

- a. *Standards and specifications*: May need FDA approval.
- b. *Customer*: The client would prefer the model to be inexpensive, light, and easy to read.
- c. *Patient-related concerns*: Must be able to be easily cleaned. Possibly dishwasher safe.