



Project Number: P14026

TESTING A PORTABLE EMERGENCY VENTILATOR

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ABSTRACT

A Portable Emergency Ventilator (PEV) provides ventilation to a person who is incapable of breathing on his or her own. In the early 1990's such a device was developed by Jeff Gutterman and Roman Press. The device was then passed on to senior design teams 13026 and 13027 for further development. As the technology developed there became a need for a system that was able to measure and record the performance of the device. The main objective of this project is to design and develop a system to test and record performance measurements of team 13027's PEV and draw conclusions to the effect that it would have on a patient.

INTRODUCTION

A Portable Emergency Ventilator is a device that provides ventilation to a person who is incapable of breathing on his or her own. The device's ability to provide air to a patient's lungs could potentially save a patient's life in an emergency situation if the device is working properly. However, the human respiratory system is sensitive and can easily be damaged by such a device. The size and strength of a person's lung is dependent on the person's age and health. Therefore, if the device is not correctly calibrated or designed, it could over-inflate the lungs of a patient or allow the lungs to collapse.

In the early 1990's Jeff Gutterman and Roman Press developed a PEV called the MEDIRESP III. When the MEDIRESP III was designed, its competitors were able to perform under three different modes: constant mandatory ventilation, manual mode, and assist mode. In order to compete with competitors, the MEDIRESP III added a CPR mode and provided air from the surrounding environment rather than an oxygen tank. In 2012, the project was passed on to a Rochester Institute of Technology senior design team, 13026. Team 13026 was tasked with the objective of developing the MEDIRESP IV a PEV that included the functionality of the MEDIRESP III while incorporating modern technology and making it more user friendly. In 2013, the project was passed on to a second senior design team, 13027, with the objective to update the PEV with modern technology. This would allow the MEDIRESP V to be lighter, more efficient, and easier to use.

Before the MEDIRESP V can be manufactured for industrial use, the PEV must be tested. It is important that the customer knows if the device operates in a manner that would support the human respiratory system. This is why as team 13027 began to build their prototype, senior design team 14026 was formed. The goal of team 14026 was to design and build a system to test and record the performance of 13027's MEDIRESP V. The system will measure

and record flow rates and pressure levels while providing a way to make adjustments to lung compliance and airway resistance in order to simulate the human respiratory system under both normal and diseased conditions.

The expected end result is to provide a testing system that models the human respiratory system and quantitatively characterizes 13027's MEDIRESP V. As a result, the analysis obtained by the testing system will determine whether the MEDIRESP V meets ISO, ASTM, and FDA standards. A final summary of the results will indicate whether the PEV is ready for market. Team 14026 is only responsible for testing the performance measurements of the MEDIRESP V, not its durability or other physical characteristics.

DESIGN PROCESS

There are two major components in the design of the testing system: measuring the MEDIRESP V's outputs and creating a method of modeling the human respiratory system. Measuring the outputs would allow the team to determine if the PEV is performing at the flow rates and pressure levels that team 13027 claimed.

Measuring Air Flow

The goal of measuring air flow is to determine if the MEDIRESP V is outputting air at the given rate. At the end of 13027's project, team 14026 gained possession of a flow meter that is owned by Jeff Gutterman. The TSI Mass Flowmeter 4040 has a measurement range between 0.0 and 300.0 Std L/min. An accuracy of 2% of displayed readings, or 0.05 Std L/min, whichever is greater, at standard conditions (21.1 °C and 101.3 kPa). The response time is less than 4 msec with 63% of final values at full scale. This flow meter can also be used with LabView to collect data. After doing some benchmarking, the team found that these performance specifications were within the range needed to evaluate the MEDIRESP.

Measuring Pressure

The pressure sensors used to measure the performance of the MEDIRESP needed to be able to identify a low pressure range, between 0 and 108 cmH₂O. This is the pressure range that an adult lung is capable of handling. Two pressure sensors would be needed. One to measure the direct output of the PEV and the other to measure pressure as the lung fills with air. The first pressure sensor acts as a check on the pressure reading that the MEDIRESP's user interface gives. The second pressure sensor detects if the pressure going in the lungs is within an appropriate range. The MEDIRESP must provide enough air to keep the lung from collapsing while at the same time ensuring that it does not over inflate the lungs. In order to comply with ISO and ASTM standards, the MEDIRESP must also trigger an alarm when the pressure inside the lungs is too high.

Silicon Microstructures' pressure sensor SM5470-015-G-B was chosen for the team's prototype. The sensors measure a pressure range between 0 and 1.5 psi or 0 and 105.46 cmH₂O. The operating supply voltage is 5V and can operate between -40°C and 85°C. The pressure sensors can also be read by LabView with the use of a DAQ board and an op-amp.

The team chose to use an EMANT300 DAQ Module to connect the board that the pressure sensors would be mounted on to the computer that would read in values to LabView. The DAQ was low cost, had a USB connection, was LabView compatible, had single channel 16 bit waveforms at 2,500 samples per second, and 6 analog I/O channels. These specifications more than covered the team's needs in order to make the pressure sensors and computer communicate.

In order for the pressure sensors to be able to be read by the DAQ, the team needed an op-amp buffer. The op-amp would raise the voltage output of the pressure sensors to a high enough voltage to be read by the DAQ. The team chose to use a Texas Instruments' LM741 Operational Amplifier. The op-amp was wired as a voltage follower and the resulting gain was one.

The Connection to the PEV and Tubing

When 13027 designed the MEDIRESP V, they designed it to connect to a specific type of medical hosing to connect the PEV to the face mask. Team 14026 decided that since this is the tubing used before air gets to the human respiratory system, it should also be used before it gets to their model of the respiratory system. By doing this the team is able to determine if the patient's lung receives the appropriate amount of air.

Not only did the PEV need to be able to connect to the team's prototype but it also needed to have a path for the air to follow. The team chose to use ½ inch diameter PVC tubing. PVC tubing also fits snug with the type of connections the MEDIRESP already uses.

When the team calculated if the flow could be assumed laminar in the PVC, they found that $Re_{max}=20.83$ using Equation 1 at STP. Since this is less than 2,300 the team could assume flow was laminar.

$$Re_{max,pipe} = \frac{\rho V D}{\mu} \quad (1)$$

Inhalation

One feature of the MEDIRESP is the assist mode. When the PEV is in assist mode, it will provide a breath to the patient when it senses the patient gasping for air. A gasp for air or a sudden inhale is recognized by the PEV during an instance of negative pressure. The team needed to design a way to simulate this negative pressure in a way that was measurable and repeatable. The team chose to use a syringe to cause this change in pressure. When the syringe is pulled on, it will remove air from the system resulting in a measurable pressure drop. Syringes come in many different sizes and are accurately marked with respect to the volume displaced, making this test measurable and easy to repeat.

In order to make the inhale as repeatable as possible, the team also chose to automate the movement of the syringe. By doing so, the team could determine the rate at which the air is being inhaled. The team chose to accomplish this by using a linear actuator because an actuator is relatively simple to control. Firgelli Automation's 140mm Linear Actuator allows a maximum speed of 32 mm/sec or about 2 in/sec when driving a load of less than 40N. The actuator can also be controlled by LabView through use of Firgelli Automation's Linear Actuator Control (LAC) board and a USB cord.

The Trachea and Air Flow Resistance

In the team's research of the human respiratory system, they learned that the trachea causes a resistance that limits the amount of air that can reach the lungs. This resistance should be between 19 and 27 cmH₂O/L/sec for a healthy adult. In order to simulate this resistance the team decided to create a pressure drop before the air reaches the lungs. Although there were a number of ways this could have been done the team chose to build orifice plates to act as resistance. The orifice plates could be made out of aluminum, a relatively cheap and easy to work with metal. Multiple orifice plates would allow the team to test the MEDIRESP under different resistances and measure the performance. The diameters of the holes for the orifice plates were determined by using Equations 2, 3 and 4. By plugging in $\rho Q = m$ and solving for A_2 the theoretical diameter sizes could be determined. Q represents the flow rate, m the mass flow rate passing through the plate, and ΔP the pressure difference between the sides of the orifice plate. Note also that the difference between A_1 and A_2 is that A_1 represents the area of the original piping leading up to the entrance of the orifice plate while A_2 represents the cross-sectional area of the orifice itself. The team successfully completed orifice plates that represent three different resistance values 5, 15, and 50. These resistances have been experimentally determined to be 5.22, 15.33, and 51.74 respectively.

$$\text{Resistance} = \frac{\Delta P}{Q} \left[\frac{\text{cmH}_2\text{O}}{\text{L/sec}} \right] \quad (2)$$

$$m = \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2\rho\Delta P} \quad (3)$$

$$A_2 = \sqrt{\frac{(\rho Q)^2}{2\rho\Delta P + (\rho Q)^2 \left(\frac{1}{A_1}\right)^2}} \quad (4)$$

The team could connect and change the orifice plate being used in the system by using flanges, o-rings, bolts, and nuts.

The Lung

While researching the human respiratory system the team learned that there is no material quite like a lung. The team investigated a number of ways to model the lungs and ultimately decided on using a Siemen's adult lung. This lung was made available to the team by Mary Murphy for free so the team did not need to purchase one of their own. Siemen's lungs are relatively expensive and according to 13027's user manual the MEDIRESP V was designed for adult use only.

Even though these lungs are used to model an adult lung in industry, they are only designed to show the average adult lung. There are many reasons why a person may need the help of a PEV. All of these people's lungs are slightly different based on their age and health. In order to address these differences the team decided to find a way to vary lung compliance. The method that the team decided on was placing weights on top of the Siemen's lung. The weight will add additional pressure on the lung as the lung attempted to inflate and would change the compliance of the lung.

Exhalation

In order to model the respiratory system and prevent over inflation of the Siemen's lung, the system needs to release the air in the lungs. This needs to happen in a controlled, timed manner in order to model the respiratory system. A solenoid valve would allow the team to do this. Coast Pneumatics' solenoid valve part LVM11-5A-1-6-Q

is fully operational within the team's pressure range and will fit inside of 3/8 inch tubing. It is also LabView compatible with the use of Mouser's low power relay driver and National Instruments' low cost USB digital I/O device.

Mounting and Protecting the System

Since the testing system is long in length, the final assembly must be easy to assemble and disassemble so the project can be stored. The system is broken into sub-assemblies with individual wooden mountings that can be assembled together when in use. The individual circuit boards and sensors are protected from harm in small plastic boxes that can be assembled to the mounts.

EXPERIMENTAL SET-UP AND PROCEDURE

There are two major parts of this project: developing and building a testing system for the MEDIRESP V and collecting and analyzing data on the MEDIRESP V. Before the team could collect and analyze data, they needed to prove that their testing system would work as expected. This was done by testing individual sub-assemblies.

Pressure Sensors

Pressure sensors send a voltage value to the computer that is relatable to a certain pressure. This means that the pressure sensors can be calibrated using a manometer. The manometer was connected to the pressure sensor that was being tested using heat shrink tubing. The open end of the manometer would then be raised until the water level dropped 1 cm. Theory says that this water level drop will increase the pressure 0.01 psi each time it is done. The voltage value of the pressure sensor read by LabView was recorded at each point and then put into an Excel document for analysis.

Orifice Plates

In order to test that the orifice plates created a pressure drop that was true to the theoretical calculations, the team needed to test the pressure drop across each orifice plate. The team did this by connecting the MEDIRESP V to the face mask tubing, the tubing to the flow meter, and the flow meter to the orifice plate sub-assembly. A manometer was connected to the orifice plate sub-assembly across the orifice plate. The team then took three samples of flow rate measurements and pressure readings for three different flow rates on the MEDIRESP V. The results of this testing were then compared to the theoretical results that were calculated.

Lung Compliance

Lung compliance is characterized by the relationship between volume in mL and pressure in cmH₂O. Compliance can be varied by placing different amounts of weight in a box on top of the lung. The box in this experiment weighs 65 g. The weights vary in mass. The set-up for this test is to have the MEDIRESP V connected to the final assembly of the system. The weight in the box would vary, varying the compliance of the lung.

Leak Tests

The system is designed with the intent of seeing if the MEDIRESP can get air from the initial output of the PEV to the lungs of a patient. This means that the system cannot have any leaks that could cause a loss of pressure or air flow. In order to verify that the system had no leaks the team performed several leak tests. The first type of leak test consisted of using dish soap to check for leaks at the connecting points of the subassemblies in the system. When dish soap covers a hole and air is pushed through the system while the exit point is covered, bubbles will appear where the hole is located. If there are no bubbles, then there are no leaks. Air was pushed through the system using the manual mode of the MEDIRESP V.

The second type of leak test tested the orifice plate sub-assembly for leaks. This test was set-up by connecting the MEDIRESP V to the face mask tubing and the tubing to the orifice plate sub-assembly. The holes in the orifice plate sub-assembly for the pressure sensor connections were connected to each other using a piece of tubing. This would prevent leaks at these points and allow the team to test the tight spaces between the flanges. The orifice plate sub-assembly was submerged in a sink full of water. As air is pushed through the system while the exit point is covered, bubbles will appear where there are leaks. If there are no bubbles, then there are no leaks. Air was pushed through the system using the manual mode of the MEDIRESP V.

The last type of leak test tested the final assembly for leaks. This test was conducted using the same method as the initial leak test. Dish soap was placed around the connection points of the final assembly as air was pushed through the system. If bubbles appeared at the surface, then there was a leak at that point of connection.

RESULTS AND DISCUSSION

Pressure Sensors

Based on the data collected during testing, the team was able to produce a best curve line for each pressure sensor. Three tests were performed for each pressure sensor that resulted in three separate lines relating voltage to pressure in cm of water for each sensor. These three lines were averaged and given a best fit line in Microsoft Excel in order to determine the exact voltage to pressure relationship for each. Equations 5 and 6 were used to calculate changes in pressure. The pressure sensor in front of the orifice plate assembly is represented by Equation 5. The pressure sensor that follows the orifice plate is represented by Equation 6. Where, y is cm of water and x is in volts, given by the sensors.

$$y = 1201x + 0.0382 \quad (5)$$

$$y = 1009x + 0.0328 \quad (6)$$

Orifice Plates Empirical Results

When the team tested the pressure drops across the R = 5 orifice plate, they found that the median flow rate was 18.58 Lpm. The upper bound flow rate is 22 Lpm and the lower bound flow rate is 11.04 Lpm. This is about a 4.5 percent deviation from the theoretical calculations that were performed for the design point of median flow. The orifice plate that has a resistance value of R=15 had an upper bound flow rate of 22.74 Lpm, an average flow of 17.93 Lpm, and a lower bound flow of 10.81 Lpm. This resulted in a percent difference in pressure drop of about 2.17 percent. The next orifice plate had an R value of 50. The team found that the median flow rate was 19.80 Lpm. The upper bound flow rate was 23.30 Lpm and the lower bound flow rate was 10.41 Lpm. This is a 3.49 percent difference from the theoretical calculations of pressure drop that were performed.

Leak Tests

During the first series of leak tests, the team found no bubbles in the soap indicating no leak at the connection points of the sub-systems. The second series of tests, found that no bubbles were made as the orifice plate system was submerged under water. During the last test, the team heard a leak in the system at the connection point of the lung. When the team pushed the lung into the connector more the noise stopped. The dish soap was then applied; no bubbles or leaks were found.

Flow Rate

The MEDIRESP V is designed to deliver a breath at different maximum flow rates. The maximum flow rate can be adjusted by the user by turning the appropriate dial. The team measured the accuracy of the MEDIRESP V's maximum flow rate by connecting it to the testing system. Table 1, shows the percent error of the MEDIRESP V display at different settings with a trachea resistance of 5. Each average is determined by a sample size of 5.

PEV Display (LPM)	Average Max Flow Rate (LPM)	PEV Volume (mL)	Standard Deviation	% Error	PEV Display (LPM)	Average Max Flow Rate (LPM)	PEV Volume (mL)	Standard Deviation	% Error
12	11.1	250	0.3	8%	24	17.7	250	0.5	36%
12	12	380	0.5	0%	24	19.1	380	0.3	25%
12	11.4	780	0.4	5%	24	18.8	780	0.1	28%
15	13.2	250	0.1	14%	28	17.4	250	0.4	61%
15	13.4	380	0.1	12%	28	18.8	380	0.3	49%
15	13.2	780	0.1	14%	28	19	780	0.1	47%
18	15.4	250	0.1	17%	32	17.1	250	0.2	87%
18	16.1	380	0.1	12%	32	18	380	0.1	78%
18	15.9	780	0.1	13%	32	18.7	780	0.1	71%
21	16.9	250	0.2	24%					
21	18.5	380	0.1	13%					
21	17.6	780	0.3	19%					

Table 1: Flow Rate Percent Error

Characterizing a Breath

A breath can be characterized by its breath rate, rise time, inspiratory time, pause, and inhale-exhale ratio. A breath rate can be determined by the wavelength of a breath. Breath rate is generally discussed in terms of breaths per minute. Rise time is the amount of time it takes for the lung to fill. The inspiratory time is the length of time the ventilator is providing a breath. The pause is the time period that follows allowing the person to exhale. The inhale-exhale ratio can be calculated by dividing the inspiratory time by the pause. Figure 1 displays the waveform of a breath with labels for key measurements.

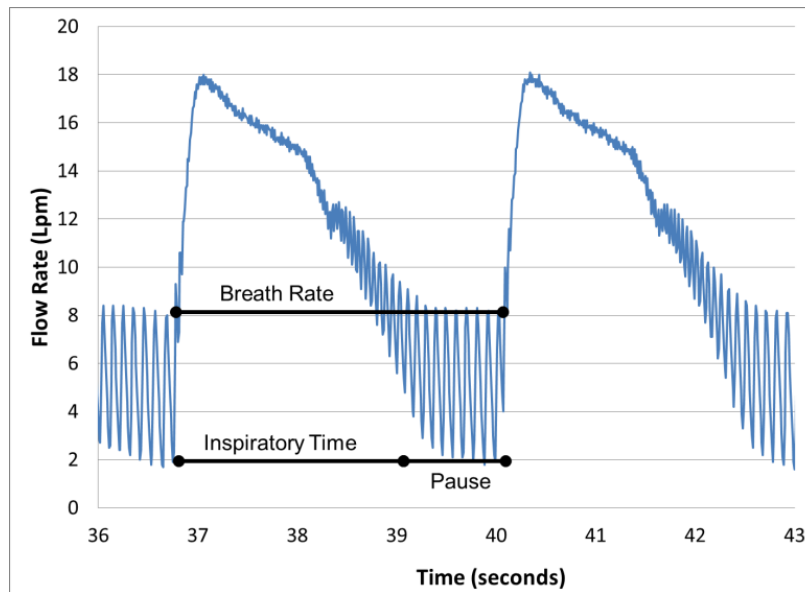


Figure 1: Example Waveform

Observing flow rates allowed the team to also determine the tidal volume of the breath. Tidal volume, in mL, is calculated by taking the sum of the flow rates during the inspiratory time, multiplying it by 1000, and dividing by 6000. Tidal volume is the maximum amount of air that can fill a person’s lung. This value changes depending on the health, age, and height of the person.

The team found that the MEDIRESP V breath rate on average ranged from 21.66 bpm to 57.02 bpm depending on the maximum flow rate setting when the PEV is set to a tidal volume of 250 mL. Based on the data collected the actual tidal volume of the PEV at the 250 mL setting on average ranged from 162.27 mL to 263.13 mL. When the MEDIRESP was set to a tidal volume of 380 mL, the team found the breath rate ranged from 14.25 bpm to 37.08 bpm. The tidal volume was found to range between 254.00 mL and 381.68 mL on average. The final tidal volume setting that was looked at was 780 mL. At this setting the breath rate ranged from 6.97 bpm to 18.27 bpm. The calculated tidal volume ranged from 472.45 mL to 652.51 mL on average.

Pressure Provided by the Ventilator

The team tested the maximum pressure that the MEDIRESP V provided going into the lung after the orifice plate. This was tested with the 5, 15, and 50 resistance orifice plates at a PEV maximum flow rate setting of 12, 22, and 32 Lpm and a PEV tidal volume of 280, 380, and 780 mL for 3 different tests. The team found that on average the maximum pressure ranged from 3.70 cmH2O to 7.46 cmH2O when entering the lung.

PEEP and Auto PEEP

Positive end-expiratory pressure (PEEP) is the pressure that the human lungs require in order to stay partly inflated. If the lungs do not have this level of pressure they will collapse, damaging the lungs. The MEDIRESP V is supposed to constantly push this PEEP level into the lungs. The absolute minimum pressure from the sensor nearest the lung was used to determine PEEP values for all tests. Of the 81 tests only three were found to lie outside the typical 2.5-6 cmH2O range. Those three tests being numbers 56, 58, and 59. The PEEP pressures for these three tests were 7.099, 2.113, and 1.206 cmH2O respectively.

When air is trapped in the lung, pressure increases with every new breath that is given by the ventilator. This makes it look like the PEEP is fluctuating when the pressure curve is observed. This fluctuation is Auto PEEP. The team found the maximum Auto PEEP by subtracting PEEP levels from adjacent breaths. The desired value for Auto

PEEP is zero. This Auto PEEP was not uniform for all breaths, which was unexpected. The Maximum Auto PEEP was found in test 7 and had a value of 1.116 cmH₂O. Twenty five out of eighty one tests had Auto PEEP levels below 0.1 cmH₂O.

Mean Airway Pressure

Mean airway pressure (MAWP) is defined by Equation 7 in cmH₂O. Where RR is the respiratory rate per minute, I is the inspiratory time in seconds, PIP is the Peak inspiratory pressure in cmH₂O, and PEEP is the positive end-expiratory pressure in cmH₂O.

$$MAWP = \left[\frac{RR \times I}{60} \right] \times (PIP - PEEP) + PEEP \quad (7)$$

The team found that the Mean Airway Pressure was between 3.62 cmH₂O and 6.03 cmH₂O. These findings gradually increased as the Lpm (Liters per minute) were increased and then increased more as the Tidal Volume was increased as well. The range for MAWP of a normal patient is 5-10 cmH₂O; therefore the PEV works within this range for higher liters per minute; when set to 12 Lpm the values of MAWP are too low. All MAWP values are too low for patients with obstructive diseases where the range for these patients is 15-30 cm H₂O. Hence, the findings depicts that the PEV works for normal patients at higher liters per minute.

Assist Mode

Assist Mode is, at its most basic level, the provision of extra air due to a drop in pressure at the patient end of the PEV system. However, it is important to know how to trigger this mode and how sensitive its triggering is. This mode was tested using the flow meter and a PCB pump which was characterized and found to remove 0.1 L per second of operation. Thus, by comparing an assisted and unassisted waveform at several different tidal volumes, the team attempted to quantify how much more flow in the assisted waveform was due to the pump and how much was due to the PEV itself attempting to meet the apparent demand for air. The PEV did not seem to respond at all, simply providing the same amount of flow in spite of what should register as increased demand.

CONCLUSIONS AND RECOMMENDATION

Performance of the MEDIRESP V

The MEDIRESP V is a relatively consistent device. The standard deviation during the pressure provided tests never ranged past 2.00. The standard deviation during the breath rate, inspiratory time, and rise time never ranged past 1.00.

The team also found that when the device was set to a tidal volume of 250 mL, the MEDIRESP V produced an actual tidal volume of a healthy child or adolescent depending on the maximum flow rate setting. A healthy child has a tidal volume between 159 mL and 210 mL. A healthy adolescent has a tidal volume between 230 mL and 279 mL. Although the MEDIRESP V is capable of hitting this range it would not be safe to use it on a child due to the possibility of over inflating the lungs. When the MEDIRESP V is set to a tidal volume of 380 mL, the actual range of the tidal volume is that of a healthy adolescent or preteen. A preteen has a tidal volume range between 300 mL and 795.1 mL. The MEDIRESP V set at a tidal volume of 780 mL has an actual tidal volume that is comparable to that of a preteen.

Although the tidal volumes described a person between ages 4 and 14 for the three settings tested, the team found that the breath rate, expressed as breaths per minute, did not necessarily correspond with the same age range. A child's breath rate ranges from 20 to 24 bpm, an adolescent's from 18 to 24 bpm, and a preteen's from 16 to 22 bpm. At the 250 mL tidal volume setting the breath rate could hyperventilate a child or adolescent. At the 380 mL setting, the breath rate could be too slow or fast for an adolescent or preteen. When the MEDIRESP V is set to a tidal volume of 780 mL, the breath rate could be too slow for an adolescent. The MEDIRESP V does not inform the user of the correct flow pressure or tidal volume that is being applied which could result in overinflating or collapsing the lungs.

In addition to the MEDIRESP V not being able to show the correct maximum flow rate or tidal volume on the display, it does not operate at a 1:2 inhale:exhale ratio. The team found that the inhale:exhale ratio changes as the user changes the maximum flow and tidal volume settings on the PEV. The team was unable to find any setting where the ventilator was providing a breath with this ratio.

The MEDIRESP V also does not respond as the user manual claims it does. The manual claims that in assist mode the PEV will administer a breath when triggered by the patient exhale. The assist mode is triggered by a negative pressure not an exhale which would show a positive pressure. The manual also states that in manual mode a breath will be administered according to the settings after a certain time period of the button not being pressed. The team sat next to the PEV for 5 minutes without touching it in assist mode and found that no breath was administered.

The MEDIRES V also does not detect compressions. The current model is simply keeping time and hoping the user is administering the compressions. This means it does not apply a breath to the user after not seeing a compression for over 3 seconds like the user manual claims.

Future Work for the Testing System

In terms of the testing system the team was able to characterize different aspects of the MEDIRES V's accuracy and was able to compare it to known data to determine when the device could not be used on. The team did fall short however on being able to get a solenoid valve working to release an exhale, getting a large enough syringe to get the assist mode working, and some LabView improvements. The team found ways around these three aspects of the project but this would need to be improved in the future.

While developing the evaluation fixture it was discovered that the solenoid valve purchased through Coast Pneumatics failed to automate the process of lung exhalation. This was evidenced by the fact that the lung was incapable of completing an exhale before a new breath. In essence, the solenoid was inadequate for the design and if used would cause the lung to overinflate. This was due from the fact that the solenoid never fully opened and remained partly shut with an applied voltage. Moving forward with the design, the solenoid air control valve part # CAT66P-012-D manufactured by ARO was found more suitable. The device operates in the closed position until it receives a 12V supply to open the valve. This would require Texas Instrument's DC/DC boost converter part # TPS61080/1 to step up the initial 5V USB supply to the operating voltage of the device. The supply voltage to the device would then be controlled by pulse width modulation (PWM) through LabView to provide bursts of power during exhalation periods. This would allow the valve to be opened at specific intervals to release air build up in the lung. Note, the DAQ board features a pin fully capable of this performance. However, this solution would only be applicable for both CPR and CMV mode which operate under specific time intervals. An alternate solution would need to be implemented to control the valve for both assist and manual mode. This would require a trigger based on the completion of an inhale or when the motor is finished providing air. A further assessment reveals that the valve is rated for 7.0 cubic feet per minute (CFM). Since 1 CFM is equivalent to 28.31 LPM, this is well within the operating range for the unit under test and will allow proper throughput of air flow.

The team found that in order to continue assist mode characterization with the original design of an actuated syringe, a larger syringe and more powerful actuator would be required. It is suggested for ease of use and integration to use a syringe pump. The syringe pump comes with an actuation system stock. It was found that this syringe would have to be at least 1.3 L in order to create negative pressure throughout the entire system. The precision of the syringe pump would be unbeatable by other options. It is suggested that the AL-6A syringe pump sold by Alita Air Pump is used moving forward. This model will deliver 6LPM or 0.1L/s. The cost is approximately 90 dollars.

In terms of the programming the team was unable to implement a feature to save all tested data in a clean format with all data labeled appropriately. Instead the data must be exported separately to excel and then combined into a single excel file. The team was also unable to generate a test report from the LabView program that would characterize each test after it was performed. Depending on the future teams preferences this may be useful to implement. These shortcomings with the program were primarily due to time constraints towards the end of MSD as the year comes to a close.

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