The Pandemic Ventilator

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Background

When a new disease or virus spreads in a population that has never been exposed to that type before it is called a “pandemic”. It can affect whole continents and spread worldwide. Many authorities are concerned that the H5N1 avian flu may cause a future pandemic. Some of the people affected by the avian flu will require short term assistance from a ventilator to survive. If an avian flu pandemic were to occur in Ontario, up to 118% of our hospital ventilators would be required just to assist pandemic victims.[1] This shortage of ventilators would force doctors to deny service to patients who need a ventilator, which would create an ethical dilemma. Some solutions have been proposed to this potential problem. Manual ventilators have been suggested, but putting a healthy person next to an infected person to assist their breathing could cause more infections in the healthy people. Splitting the air lines from one normal ventilator and putting two patients on one machine has also been suggested, but splitting the lines nullifies all the monitoring and alarm capabilities of a medical grade ventilator.

Purpose

The pandemic ventilator must be built using simple, reliable and readily available parts and materials. It has to be easy to build and maintain in the event of a flu pandemic so it could be used to supplement the existing supply of medical grade ventilators if a shortage occurs.

[1] Ontario Ministry of Health and Long Term Care: Ontario Health Plan for an Influenza Pandemic. July 2007

Hypothesis

I will build a pandemic ventilator using the same material constraints that would apply during a pandemic to determine if it is feasible to build one with basic tools and experience. The unit will be tested to see if it can meet the specified requirements.

Procedure

The basic design is similar to the original concept published at the Pandemic Ventilator Project website. I think that the published design had some shortcomings that I thought could be improved on. Instead of the hinged based bellows system, I used a vertical sliding bellows system. I replaced the plastic bag with a stronger PVC bag. I also used an analog pressure transducer instead of the manometer. I replaced the magnetic switches with industry standard mechanical limit switches. I added a flow control valve to adjust the inspiratory to expiratory ratio. These changes were implemented to make the ventilator more reliable and install more features.

I constructed it using Bosch strut and plastic panels. I used an Allen Bradley Micrologix 1500 Programmable Logic Controller (PLC) to control the valves and relay information to the PC. The valves are standard direct acting solenoid valves. I used standard plumbing pipes and fittings to connect the elements together. I used a 5 volt low pressure transducer to monitor the patient inspiratory pressure. The PLC is programmed with basic ladder logic.

Once constructed, I used a Puritan-Bennett 0612 test lung to evaluate the ventilator and measure maximum pressure and airflow. I adjusted the weight on the bellows and the flow characteristics to make it operate within the normal pressure and flow limits of a regular ventilator.

Results

In order to get the ventilator to operate correctly, I needed to modify the original design, and do some troubleshooting to achieve reliable operation. A 4.5 kg weight was required on the bellows plate. This generated a maximum pressure equivalent to 22 cm of water and this is within a safe operating range. The tidal volume, which is the volume of air exchanged in each cycle, was about 0.4 liters. The minute volume, which is the total volume of air exchanged in one minute, was about 7 liters. These are within the normal therapeutic ranges for a ventilator. Maximum pressure can be adjusted by changing the bellows weight. Changing the setting of the limit switches and the flow controller can adjust volume. The ventilator has been operating reliably during the testing phase.

Testing

Functional testing was done on the ventilator in order to show that the design features would work and to see how accurately they were calibrated.

Test of minute volume and total volume monitor accuracy

The tidal volume was measured over a two minute interval using a Boeringer ventilator spirometer. The spirometer measured 10.6 liters of air volume. The ventilator recorded 10.7 liters of air volume. The calculated minute volume is 5.3 liters per minute. The ventilator displayed 5.0 liters per minute for minute volume.

Test of pressure monitor accuracy

The patient circuit pressure was measured using a Checkmate ventilator pressure monitor. The circuit was pressurized at different pressure intervals and the readings from the Checkmate and the ventilator were recorded.

Reading	Checkmate pressure cm H_2O	ventilator pressure cm H_2O
1	10	12
2	20	21
3	30	30
5	40	41
5	50	49

Test of high patient pressure alarm

The high patient pressure alarm limit was set on the ventilator. An alarm condition was created by pressing down on the lung simulator during the inhale portion of the ventilation cycle. The visual alarm on the monitor turned on.

Reading	high pressure patient alarm setpoint cm H_2O	alarm test Checkmate pressure reading cm H_2O
1	40	40
2	45	46
3	50	51

Test of patient line occlusion alarm

The patient line was occluded between the inhale valve and the patient connector. The alarm occurred within three seconds. The audible alarm sounded and the visual alarm indicator turned red which indicated a malfunction. The occlusion was removed, the alarm was then reset with the reset switch and the ventilator continued to run without error.

Test of loss of air pressure source alarm

The pump was unplugged to simulate a loss of air pressure. An alarm occurred within two seconds. The audible alarm sounded and the visual alarm indicator turned red which indicated a malfunction. The pump was reconnected, the alarm was then reset with the reset switch and the ventilator continued to run without error.

Test of respiratory rate monitor accuracy

The number of respiratory cycles was counted over a two minute interval. The number of cycles recorded was 27. The number of cycles displayed by the ventilator was 27.

Conclusions

I was able to achieve operations similar to a normal medical ventilator. Multiple copies of the ventilator would be very easy to build to meet the needs of a ventilator shortage during a pandemic. With more development time I can improve the monitoring, display and alarm systems.

Applications

An additional use of the pandemic ventilator design or something similar to it could be a sustainable solution for a ventilator for use in the third world. The design of this ventilator is simple enough that it could be built, maintained and used with minimal experience and training.

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Bibliography

Current WHO Phase of Pandemic Alert [Internet]. [updated 2007 Jun 09] Geneva (CH): World Health Organization; [cited 2008 Mar 28]. Available from: http://www.who.int/csr/disease/avian_influenza/phase/en/index.html

Stand On Guard For Thee; Ethical considerations in preparedness planning for pandemic influenza [Internet]. [updated 2005 Nov] Toronto (ON): University of Toronto Joint Centre for Bioethics Pandemic Influenza Working Group; [cited 2008 Mar 28]. Available from: http://www.utoronto.ca/jcb/home/documents/pandemic.pdf

Graansma, Clarence. Preliminary Layout for Open Source Pandemic Ventilator Design [Internet]. [updated 2007 Mar 20] Kitchener (ON): Pandemic Ventilator Project; [cited 2008 Mar 28]. Available from: http://panvent.blogspot.com/2007/03/preliminary-layout-for-open-source.html

Ontario Health Plan for an Influenza Pandemic [Internet].[updated 2007 Jul] Toronto (ON): Ontario Ministry of Health and Long Term Care; [cited 2008 Mar 28]. Available from: http://www.health.gov.on.ca/english/providers/program/emu/pan_flu/pan_flu_plan.html#whole

Amitai, Allon. 2006. Ventilator Management. eMedicine [Internet]. [cited 2008 Mar 28]. Available from: http://www.emedicine.com/emerg/TOPIC788.HTM

Neymen, Greg MD, Irvin Babcock, Charlene, MD. 2006. A Single Ventilator for Multiple Simulated Patients to Meet Disaster Surge. Academic Emergency 13:1246–1249

Guidelines for Acquisition of Ventilators to Meet Demands for Pandemic Flu and Mass Casualty Incidents [Internet]. [updated 2006 May 26] Irving (TX): American Association for Respiratory Care; [cited 2008 Mar 28]. Available from: http://www.aarc.org/resources/vent_guidelines.pdf

Elayaperumal, Santhi; What is biomedical engineers' role in medical technology in the developing world [Internet]. Minneapolis (MN): Department of Biomedical Engineering University of Minnesota; [cited 2008 Mar 28]. Available from: http://www1.umn.edu/bme/pdf/Santhi_full_story.pdf

Altered Standards of Care in Mass Casualty Events [Internet]. [updated 2005 Apr] Rockville (MD): U.S. Department of Health and Human Services, AHRQ Publication No. 05-0043; [cited 2008 Mar 28]. Available from: http://www.ahrq.gov/research/altstand/altstand.pdf