# Control for Low Cost Hardware

## Disclaimer

**This example may not represent an implementable design, and no validation has been done. This purpose of the example is to provide a starting point for designers working ventilators showing how interfacing between the real-time controller and the system model can be done, how a real-time controller can be defined in Simulink® and Stateflow™ and how a full system model can be used to support the design process.**

**Note: this control design uses pressure measurements but is not a traditional pressure-control mode of ventilation.**

## Measurements

In this example, the control system only relies on a pressure measurement and no flow measurements. This single pressure measurement enables monitoring of minimum and maximum pressures which enables some very simple automated adjustments of air supply set point. In practice, state-of-the-art and medically approved ventilators will also have measurement redundancy plus also measure one or more flow rates to enable fault detection and isolation plus more advanced control techniques.

The pressure sensor is assumed to provide an analog voltage level that is proportional to pressure, the sensor outputting 0.5 volts at atmospheric pressure, and 4.5 volts for 50cmH20.

## Actuation

In this example, the air movement is driven by a fan (specifically a side channel blower) that for simplicity does not have a speed controller. Hence fan speed drops as the pressure load increases. For this particular fan, the datasheet specifies 35m3/hr at no load, and 21m2/hr when the pressure differential is 100mbar. In practice, state-of-the art ventilators are likely to incorporate closed-loop fan speed control, particularly for volume-targeted and proportional assist control modes.

Air movement is controlled via two proportional valves. The valves modelled come with an integral controller that translates an analogue voltage reference input to a valve position. Here the exhale valve is always demanded fully open or fully closed, but the inhale valve is either fully closed, or partly open, the opening set point being fixed by the controller. This set point indirectly controls the tidal air volume delivered to the patient.

An alternative configuration would be to do away with the inhale valve and modulate the fan motor speed during the breathing cycle to achieve the desired pressure and/or flow rate. This requires a motor and drive that can very quickly respond to the demanded speed, so high torque to inertia ratio.

## User Set Points and Control

The heart of the controller is a state machine that cycles the inhale and exhale valves open and closed at the desired respirator rate (breaths per minute). On top of this, the controller adds the following functions:

* The ratio of the exhale to the inhale time can be varied.
* During inhalation, once the target pressure is reached, the inhale valve closes at a rate required to keep the pressure on target.
* Protection against falling below the minimum pressure demand is achieved by closing the exhale valve if minimum pressure is reached. A minimum pressure greater than atmospheric is used to keep the lungs expanded (continuous positive airway pressure, CPAP).
* The inhalation valve has a lower opening threshold applied during the inhalation period. This threshold gets nudged up if the minimum pressure was reached during the breathing cycle. This ensures that for the next cycle the lowest pressure will be higher, and this acts to remove any reliance on closing the exhalation valve during exhalation to maintain minimum pressure.

The set point is adjusted by an external rotary dial that provides an analogue signal to the microcontroller. This is then decoded and used to drive lookup tables that set things like the respiratory rate and the minimum and maximum pressures.

The controller implementation is a proof of concept only, and is missing protections such as ensuring the valve opening fraction stays within predefined limits and fault-tolerant control modes. A deployable ventilator controller will also need to add sensor redundancy and additional control modes that use feedback to control flow rates and to take account of patient voluntary breathing.

**Please remember this is intended as an example for people to build on if they are working on ventilator projects and is not a working design in itself.**