



Controller Configuration

This walk through assumes you have a functionally complete ventilator that still needs to be checked for final assembly, geometric configuration and calibration coefficients. The controller will record and remember all of the coefficients in a configuration file onboard, and these coefficients will override the default settings in the source code.

You can confirm the CPAP performance without a control module.

You can configure the valve geometry without the CPAP modules.

The pressure and flow configuration requires both the air supply from the CPAP modules and the flow system of the control module.

You can handle the configuration file with the (r)ead, (w)rite, and (W)ipe commands from the Serial Monitor of the IDE. The config file is read on startup, but is only written with an explicit call to (w)rite. (W)ipe is only needed to allow a fresh start from defaults in the code. The config file is not overwritten when you compile and upload a new version of the code.

You can set the parameters directly with the (C)alibration, (S)ervo, and (M)odel commands if you already know the values, or you can follow the processes below to measure and record those values.

Confirm CPAP Output Pressure

1. Set both CPAP machines to 20 cm H₂O pressure output.
2. Attach a hose to the output port of the CPAP #2 housing.
3. Start CPAP #2 and close the housing.
4. Start CPAP #1 — there should now be a high volume flow coming out of the hose.
5. Immerse the end of the hose in water. (A large bucket would be ideal to limit splashing.)

The flow should continue at significant volume out the end of the hose until you reach a depth of approximately 40 cm under the water. Below 40 cm there should be no flow. If

this functions as expected, you can treat the combined steady CPAP pressure as 40 cm H₂O at normal breathing flow rates.

Reconnect the control valve system to the CPAP output port.

Configure Valve Geometry

1. Disconnect the power supply from the servos.
2. Remove valve gates from servos unless you are confident they are already positioned correctly. (Driving servos past maximum settings could do physical damage to the valves and / or servos.)
3. Connect a PC to the USB port of the microcontroller and run the Arduino IDE.
4. Open the Serial Monitor of the IDE to observe output from controller. It should be rapidly printing lines of numbers.
5. Enter "P-1". The printing should stop.
6. Enter "x" and return (all command lines end with hitting the return key) in the top line of the monitor. The valves should open. (Returning to (R)un mode requires an "R" command, step 15.)
7. Enter "h" for (h)elp. You should see a list of possible commands.
8. Enter "W99" to wipe any previous configuration file.
9. Use the "C" and "S" commands with no arguments to see the current calibration and servo settings. Confirm that "S" shows all angles to be 90 degrees.
10. Enter "w" to write the config file.
11. Apply power to the servos and they should move to the fully open 90 degree positions.
12. Enter "s" and follow instructions to set the positions for your valves.
 1. The first step will allow you to correctly place the gates for the 90 degree servo position in the middle of the range. Place the gates as close to the tubing as possible while leaving a full open area of the tubes.
 2. The next step allows you to move the CPAP valve gate angle positive or negative until it is at a maximum closure position. Do not set this value beyond the closure position, as the servo motor will strain to reach the unreachable, possibly damaging the structure, or overheating.
 3. Repeat for the PEEP valve.
 4. Ignore the Dual Valve settings unless you have that hardware configuration.
13. Enter "S" to check that the servo angle settings make sense and note the values for the future.
14. Enter "w" to write the config file.
15. Enter "R" to return to run mode. The numbers should return and the servos should actuate the CPAP and PEEP valves in turn to control the ventilator.

Configure Pressure Sensors

1. Turn off the CPAPs so there is no flow and no pressure on the sensors.
2. Enter "P-1". The printing should stop.

3. Enter "x" and return (all command lines end with hitting the return key) in the top line of the monitor. The valves should open.
4. Enter "a" and note the three voltages reported. They should all be near 1.24 volts (+/- 0.10 volts?).
5. Turn on the CPAPs and let the flow develop, then enter "a" again. All of the voltages should now be higher than the original values. If any are lower, reverse the connection polarity of their signal lines and recheck. (There are multiple locations where these connections could be reversed, or the flow elements could be installed in either direction in the tubing.)
6. Turn off the CPAPs and let the pressures and flows drop back to zero.
7. Enter "a-1" and make a note of the offset voltage values that have been set. You can check them any time with the "a" command to show measured voltages, or the "C" command to show the recorded offsets. (Note that the offsets will have changed when you reversed the connections!)

Set Scale Factor for Pressure

1. Turn on the CPAPs and block the PEEP outlet so there is a very small flow and pressure of 40 cm H₂O on the patient pressure sensor.
2. Enter "P-1". The printing should stop.
3. Enter "x" and return (all command lines end with hitting the return key) in the top line of the monitor. The valves should open.
4. Enter "a" and confirm a value significantly above the offset for the pressure measurement.
5. Enter "C" to confirm offset you set previously and a scale factor of 1.0
6. Enter "f" to display flow data. The reading shown for pressure will be the voltage about the offset from the patient pressure sensor, a value that might be 0.63 volts.
7. If you have a manometer, or other reference instrument, use it to get an even better value for the actual pressure generated by the CPAPs and use that in the next step.
8. Calculate the scale factor in cm H₂O per volt by dividing the applied pressure by the voltage, e.g. $40 / 0.63 = 63.5$ cm H₂O per volt. Write this value down for later.
9. Enter "C0,0,0,63.5" using your own scale factor in place of 63.5, then enter "C" to verify the settings. (Note that the three leading zeros don't change the offsets.)
10. Enter "w" to write the config file.

Set the Scale Factors for Flow

1. Turn on the CPAPs and add a measurement device to the outlet to the CPAP side outlet from the ventilator on the way to the patient. Restrict the output to a flow rate that is reasonable for normal operations, maybe 10 litres per minute, and insure the volume flow rate is known and steady. (If necessary, you can use an estimate for this flow and the results will still show the right shapes, while the numerical values will depend on the quality of the estimate. This can be useful for getting qualitative data.)
2. Follow the same steps as in setting the Scale Factor for Pressure, but this time we are interested in the CPAP side flow values. The result might be a value of 0.0814

for a flow of 10 litres per minute, so $10 / .0814 = 123.9$ lpm / volt for the scale factor. Write this value down for later.

3. Enter "C0,0,0,0,123.9" using your own scale factor in place of 123.9, then enter "C" to verify the settings. (This time the four leading zeros leave the offsets and the pressure scale factor unchanged.)
4. Enter "w" to write the config file.
5. Now connect the output port straight back to the return port of the ventilator to make sure the same flow rate is present on both sides of the device. Restrict the tubing so that the flow is in the right flow rate range and steady.
6. Enter "f" and you should see the flow rate for the CPAP side, maybe 11.3 litres per minute, but still a lower value like 0.1234 for the PEEP side flow. Calculate a scale factor like $11.3 / 0.1234 = 91.6$ lpm / volt.
7. Enter "C0,0,0,0,0,91.6" using your own scale factor in place of 91.6, then enter "C" to verify the settings. (This time the five leading zeros leave the offsets, the pressure and CPAP flow scale factors unchanged, while setting the final PEEP side flow scale factor.)
8. Enter "w" to write the config file.

It is important to be sure the scale factors for the PEEP side and CPAP side flows are balanced to give matching results, as the patient flow rate will be calculated from the difference between them. Independent calibration will introduce an unnecessary bias error.

Set Hardware Model and Serial Number

Use the "M" command, e.g. "M5,27" to set model 5, serial 27. Serial number will be built including the model number as model * 10000000 + serial, e.g. 50000027. Model must be 1 - 99, serial will be truncated to 1 - 9999999. Be sure to write the config file with "w" after changing the values.

Model and Serial numbers appear on the equipment name plate, and the software may perform differently if you have set the model number incorrectly.

Model 1 is obsolete.

Model 2 is obsolete, and included a single venturi at the patient interface for flow measurement. It will not operate properly with current software.

Model 3 includes two flow elements for flow measurement on both legs of the circuit, housed in the control unit. All pressures are measured on analog inputs and air supply is delivered from 2 CPAPs in series.

List of Command Menu Choices

Firmware version 0.4.5 supports these commands from the configuration or operations console and will print this list in response to any unrecognized command, including “h” for (h)elp.

Although functional for operator interaction, it is intended that the clinical operator will access all settings through the display unit.

Application specific commands include:

- a - read and display (a)nalogue voltages, averaging over n values, e.g. a10
Set offset values if n is less than 0, e.g. a-1
- A - set (A)larm condition on (positive argument), off (negative argument),
or just show condition (0 argument), e.g. A-1
- C - set desired (C)alibration offsets and scale factors for patient pressure, CPAP flow, and PEEP flow
e.g. C1.2435,1.2532,1.3121,90.3,50.4,42.1
- D - set desired (D)amping time constant for noise reduction [s], e.g. D0.1
- e - set desired patient (e)xpiratory times target, high/low limits [ms], e.g. e2500,4500,1000
- E - set desired patient (E)xpiratory pressures high/low/trig tol [cm H2O], e.g. E28.2,6.3,1.0
- f - read and display (f)low values, averaging over n values, e.g. f10
- i - set desired patient (i)nspiratory times target, high/low limits [ms], e.g. i2000,3500,1200
- I - set desired patient (I)nspiratory pressures high/low/trig tol [cm H2O], e.g. I38.2,16.3,1.0
- M - set desired hardware (M)odel and serial numbers, e.g. M3,30000001
- P - set print mode, positive for plotter mode on, negative for no console output,
0 for plotter mode off, e.g. P1
- r - (r)ead in the calibration, servo angles, and other settings from the file, e.g. r
- R - set to normal (R)un mode, e.g. R
- s - set closed/open settings for CPAP and PEEP valve (S)ervos interactively, e.g. s
- S - set closed/open settings for CPAP and PEEP valve (S)ervos, e.g. S130,180,90,140,66,98
- t - set desired inspiration/expiration (t)imes [ms], e.g. t1000,2000
- T - set breath Triggering, positive for triggering on, negative for triggering off, e.g. T1
- w - (w)rite out the calibration, servo angles, and other settings to the file, e.g. w
- W - (W)ipe out the calibration, servo angles, and other settings and return to defaults, e.g. W99
- x - open all valves and enter config mode, will not auto-return to run mode, e.g. x
- X - close the CPAP valve and enter stop mode, will auto return to run mode after reaching a time limit, e.g. X
- Z - do nothing, can be sent as a heartbeat, e.g. Z

Normal data lines start with a numeral. All command lines received will generate at least one line of text in return. A line starting with ACK indicates a recognized command was received and acted on, as described in the remainder of the line. It does not necessarily mean values were changed, as some or all may have been outside permitted limits. A line starting with NOACK indicates an unrecognized line was received. Other human readable lines can be ignored.