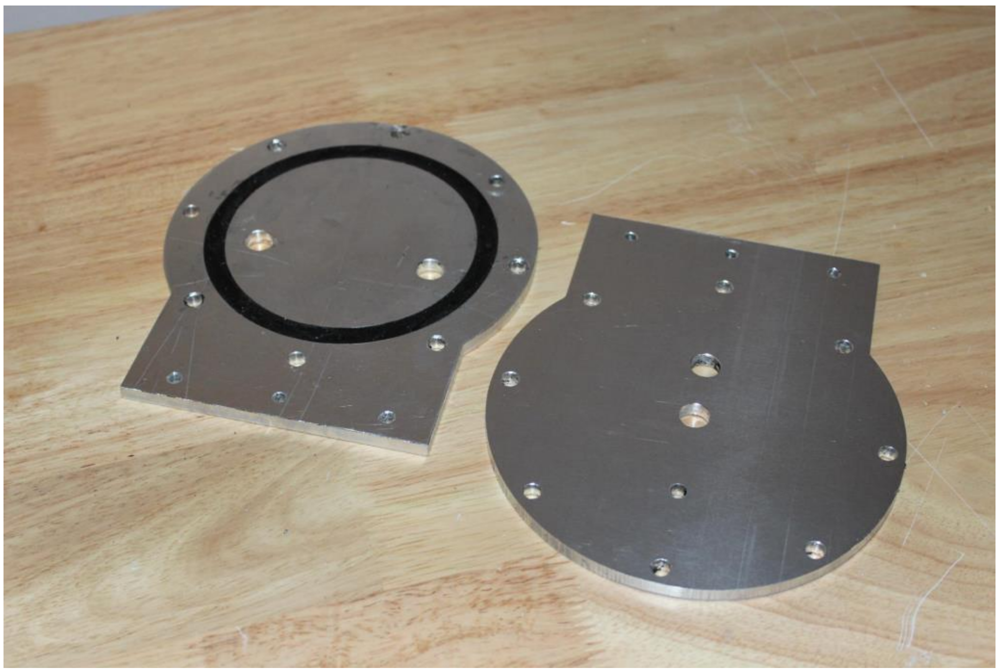
Mechanical assembly:

Notes:

- This assembly document provides tips and things to watch out for. There will be things missing in the instructions, and the CAD should be used as a reference for this.
- Machining and printing instructions are not included here. They are different for every machine. This document assumes you already have all the parts made.

1) Add silicone to the endcaps. Make sure it is 100% silicone sealant. Black silicone works better since you'll be able to see if it has sealed to the tube later. Squeeze silicone into the spot for the gasket and make sure it fills the space fully. Make sure that all other surfaces are covered with masking tape. Leave to cure for 24-48h. The final product will look like this:



2) Set the Polycarbonate for the plastic case to dry. Depending on the process and temperature used for drying this can take hours or days.

3) Make the base frame out of 2020, use the pdf for it. It can be cut to size with a miter saw and drilled with a drill press. You'll also need a set of taps. M6 fasteners hold it together.

It will look like this when finished:

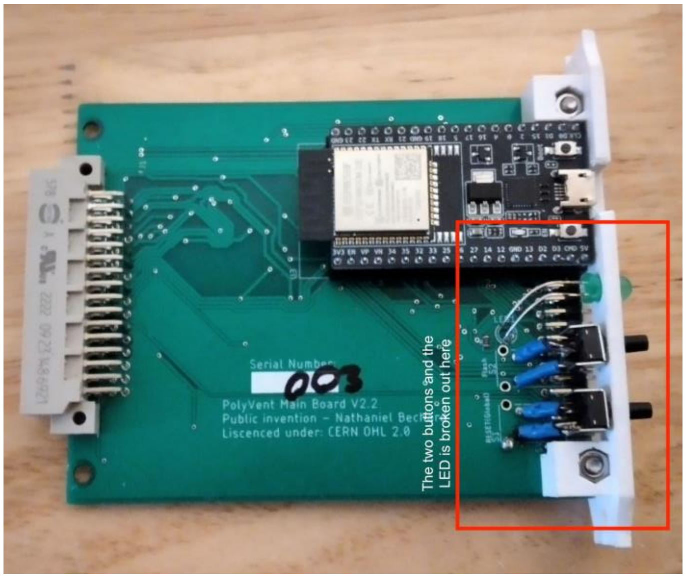
4) Mount rubber feet to the base tub. This prevents scratching.

5) Mount the base frame to the tub with M5 flathead screws. If the bottom base tub holes aren't countersunk already, you'll have to do it yourself.
6) Install rivets in the tub (it is important to do this after the 2020 frame is mounted to the base tub, otherwise it may not fit). Use double-flush rivets on the corners and nut rivets on the front and back. The double-flush rivets will need a countersink if the sheet metal manufacturing house didn't already include them. There will be 4 nut rivets and 12 double-flush rivets in total.

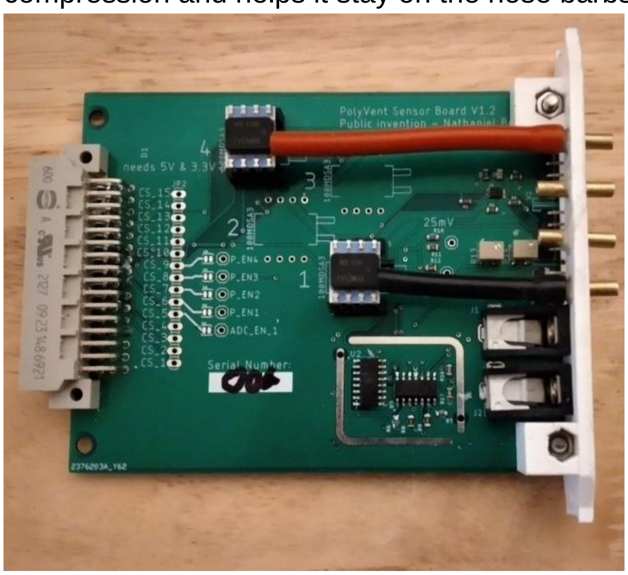
Nut rivet positions are in red, and double-flush rivet positions are in blue.

7) Make Control module and PSU enclosure:

The sensing card and main card need some modifications that aren't obvious from the schematics or CAD. The main card has a 5mm LED and two buttons broken out and glued to the front panel. It will look like this:



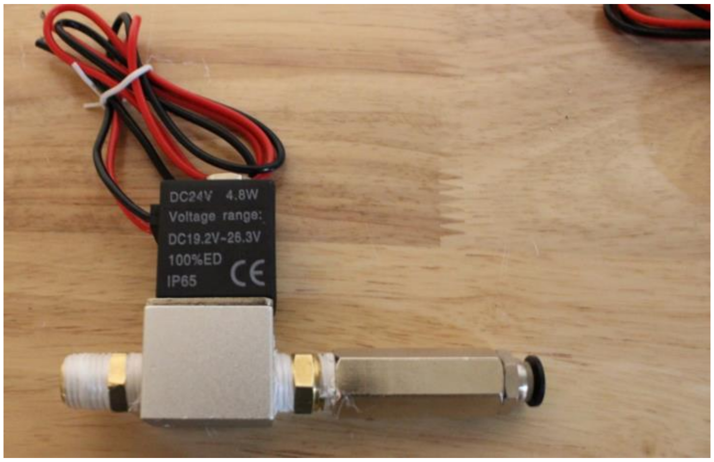
The sensing card needs some brass tubes glued in, and some flexible tubing run in it. The tubes in the image below are color coded. It is a good idea to do this. Red is used for high pressure, and black is used for low pressure in PolyVent machines. It is a good idea to make the tube slightly longer than needed, this keeps the tube in slight compression and helps it stay on the hose barbs.



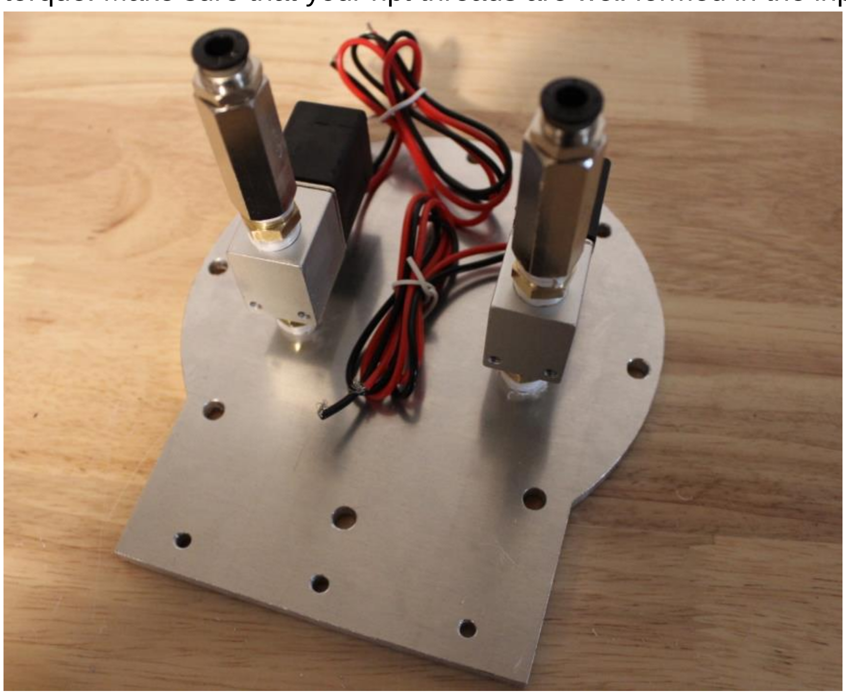
Otherwise the control module assembly is quite straightforward. Use the control module BOM and CAD to assemble this.

8) Make the gas mixing module
Once the endcaps are dry, the mixing module can be assembled.

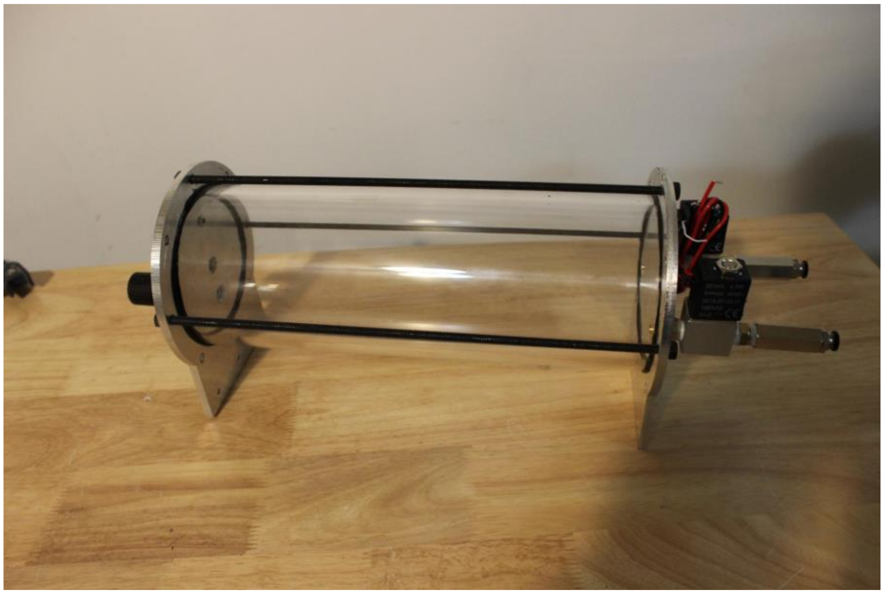
First, make two of these subassemblies. Your valves may differ, but they must be small enough to screw into the input plate (without hitting eachother). Make sure that the check valve allows flow from right to left (in the image). You may need a lot of torque to install these pipe fittings, so prepare large wrenches and a vice to hold the valve.



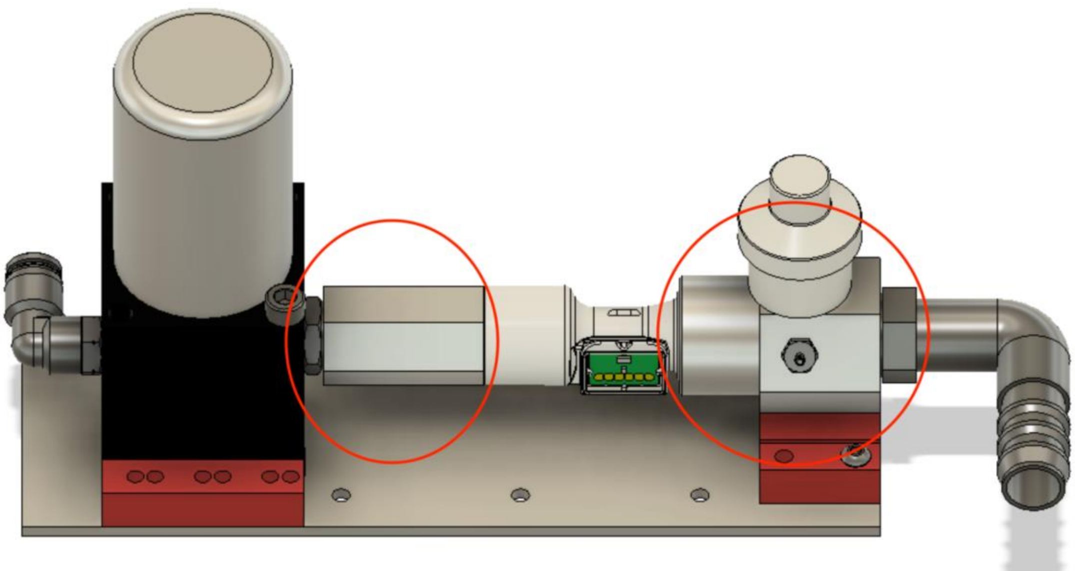
Next, you can add the valve assemblies to the input endcap. This may also take a lot of torque. Make sure that your npt threads are well formed in the input endcap.



Install the necessary hardware on the output endcap: the over-pressure valve, pressure sensor hose barb, and output coupler (8mm right-angle quick-connect fitting). This will be your last chance to clean the acrylic tube and inner endcap surfaces. Sandwich the clear acrylic tube between both plates, making sure that it only touches the silicone gaskets. Tighten the tank bolts until a seal is seen everywhere on both plates. Next, test the tank by holding 50PSI compressed air in it. Raise the pressure in the tank up to 50 PSI slowly using a pressure regulator. If the system fails, it will be due to a leaking gasket. The mixing module will look like this when done:

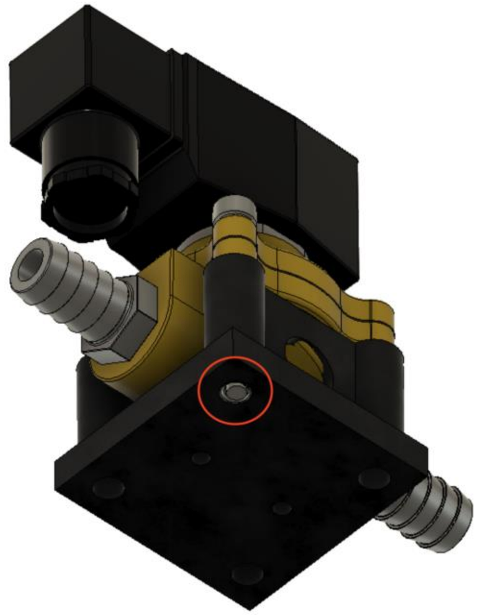


9) Make the gas drive module
Mounting the gas drive module components is quite complicated:



The flow stabilizer and manifold (shown above), need to be machined so parts can be threaded/inserted in perfectly. If they are not properly machined, the dampers (red parts) won't align with the holes in the plate. The parts need to be threaded in as shown above for everything to fit. This will take a lot of torque in the case of the part coming out of the proportional valve. The proportional valve needs to be clamped into a vice, and the flow stabilizer needs to be threaded in with a large wrench.

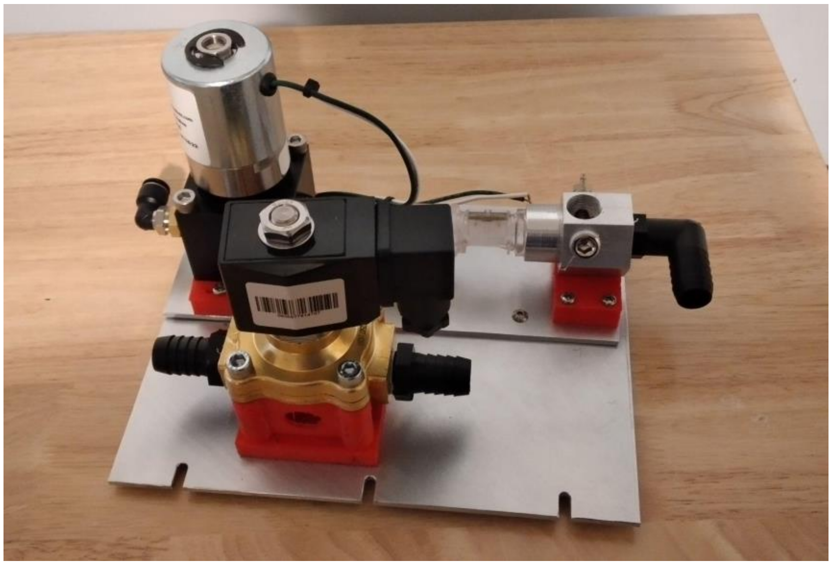
10) PIV system



Add M6 heat set inserts to the bottom of the PIV damper. To keep the valve as quiet as possible, no metal should be touching the base plate. These heat set inserts should not stick out. Next, the hose barbs should be installed on the valve and the stock M6 bolts should be replaced with 50mm M6 bolts, like so:

The PIV damper then gets mounted to the baseplate, before threading in the 50mm M6 bolts into the inserts. Make sure that the PIV valve has its output pointing left.

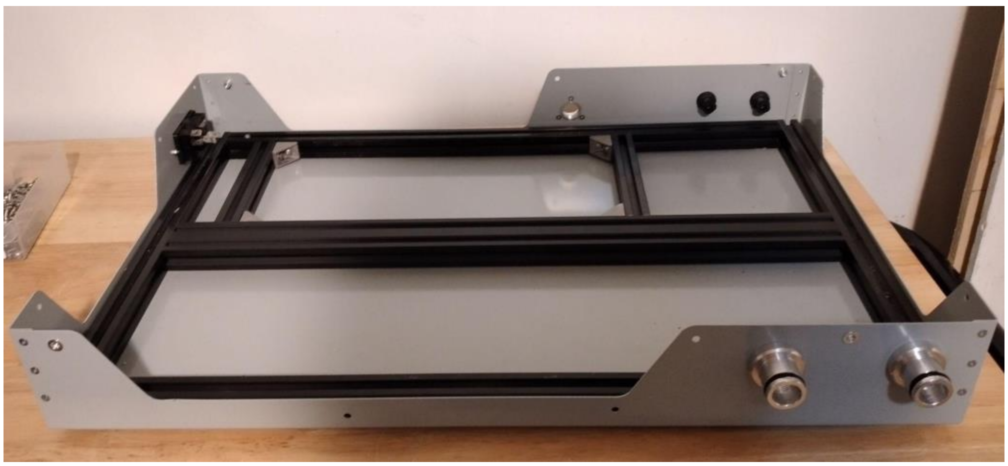
11) Mount the gas drive module on the gas drive and PIV baseplate. It should look like this:



12) Install the patient hose couplers, air and oxygen inputs, peep coupler, and power block. The power block needs M3 screws. Ideally the threads for these are tapped into the metal, but if your threads do not hold, nuts can be used to tighten the block down further.

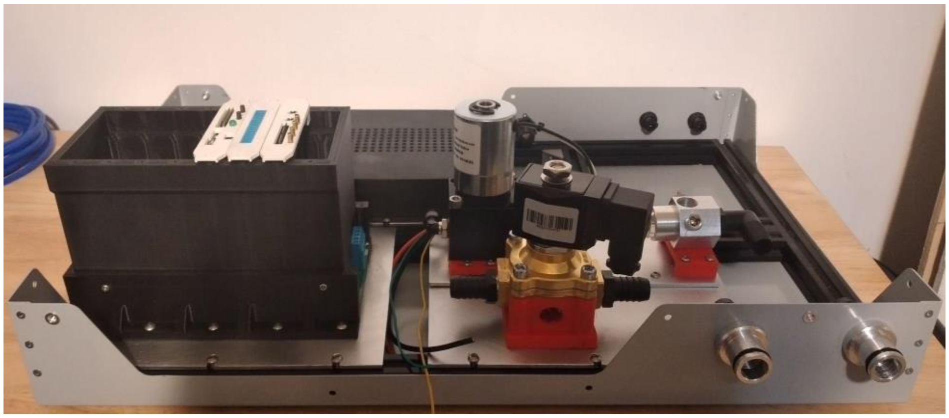
4mm long M3 bolts are used to mount the patient couplers and PEEP couplers to the frame. After this step is done, the base will look like this:

13) Add 2020 rails for the mixing module. These will be mounted with T nuts. Mount the corner brackets in the right locations (found in the cad) then add the rails. It will look like this when installed:

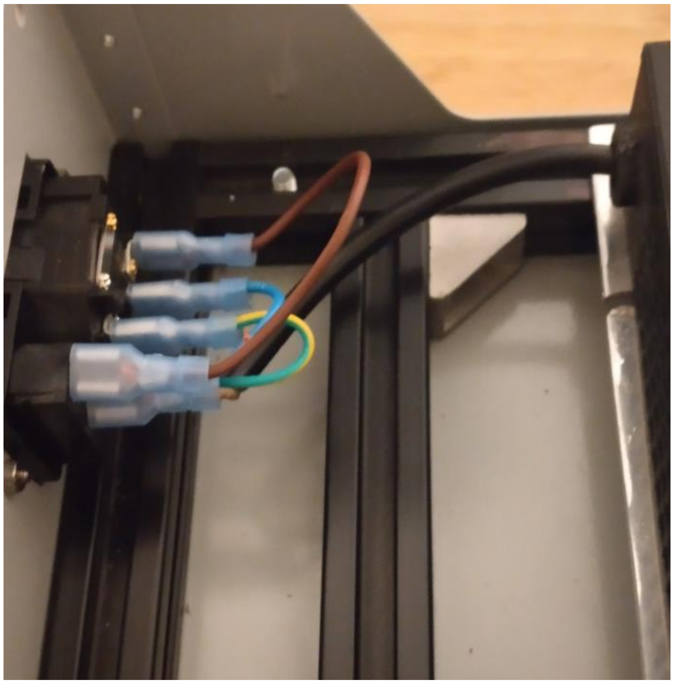


14) Add the patient coupler and PEEP hose barbs. It will look like this when done:

15) Add the control module parts, and the PIV and gas drive assembly. These are mounted on the rails with T nuts.

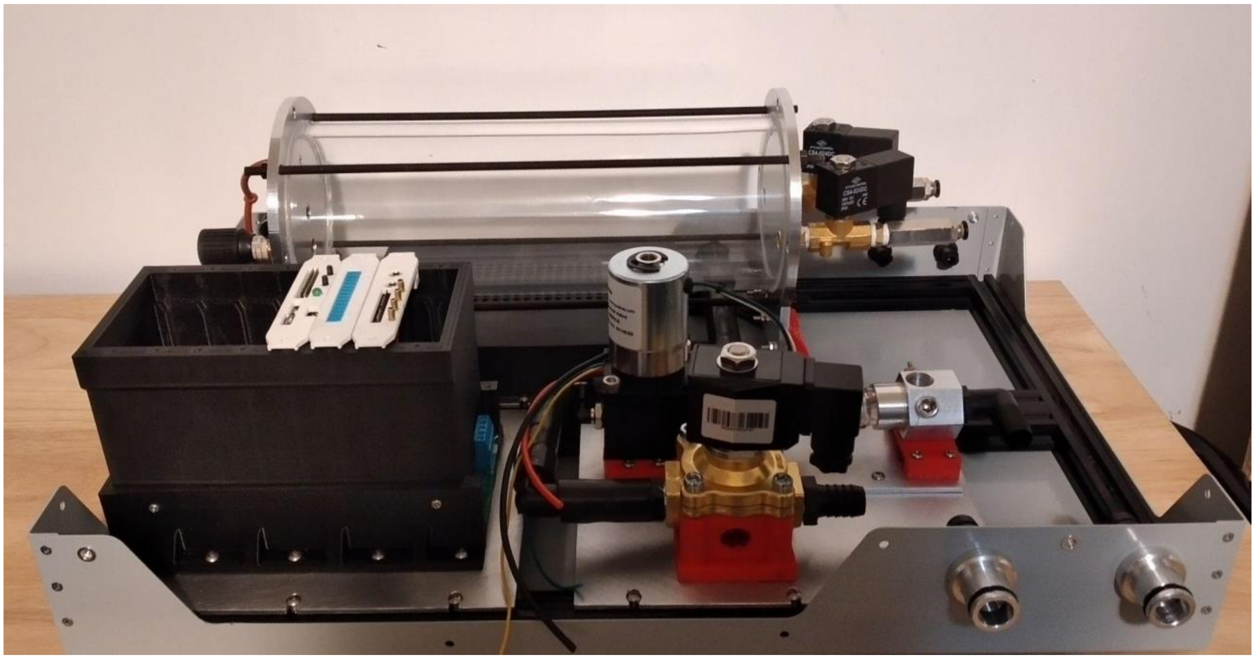


16) Wiring and tube routing, round 1:
Some wiring and tube routing is far easier to do before adding the mixing module, so they should be done now. These parts of the wiring and tube routing are: the PEEP line and the AC wiring.
Here's what the completed AC wiring looks like:



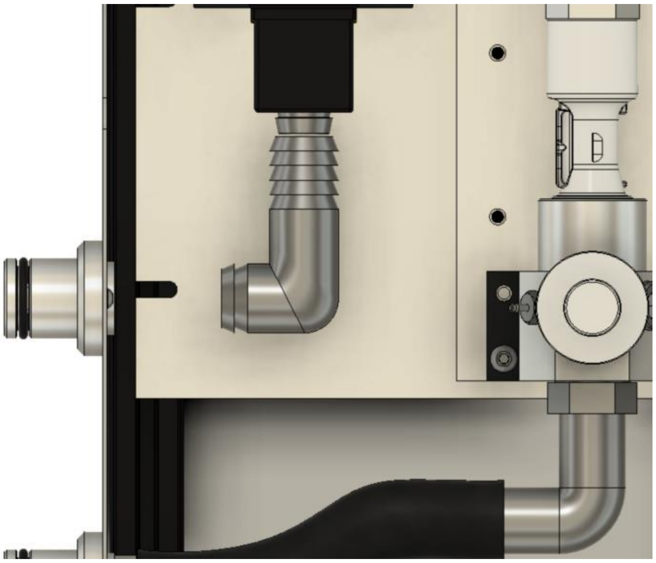
Make sure that there's enough wire to go around the mixing module when it gets installed. Your black wire should be a little longer than the one in the image.
There is also wiring in the PSU box. Since I'm not an electrician, I won't explain how you put this all together, you'll just have to know how to do it, and accept any risks that come along with making your own wiring.
The PEEP line is made of ⅝ inch silicone tubing, use the CAD for reference.

17) Mount the Mixing module on its rails with T nuts.

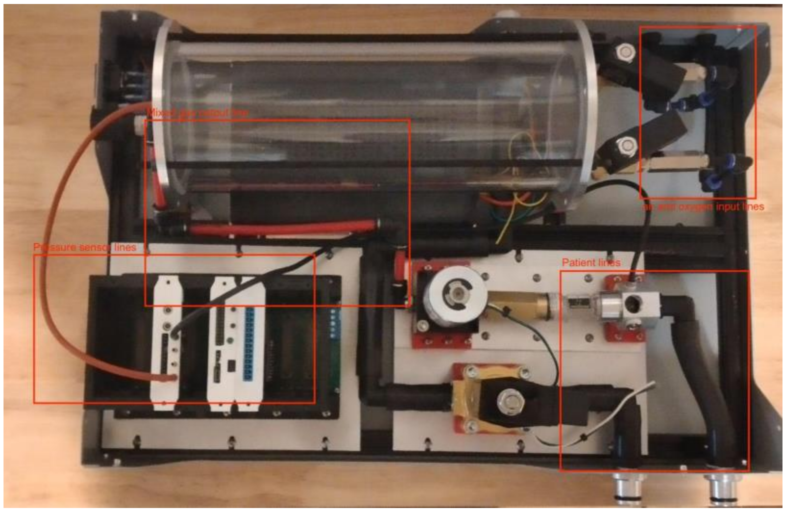


18) Rout the rest of the tubing

This is fairly straightforward, except for one connection. The 90 degree coupler in the Patient out to PEEP line has to be modified like so:



The final tube routing will look like this:



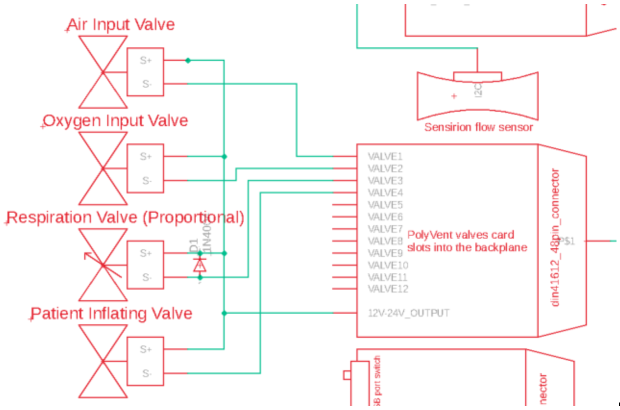
Make sure that you low-pressure sensing line goes to your low-pressure pressure sensor and that your high-pressure sensing line goes to your high-pressure pressure sensor. Also make sure that you leave some slack in the sensing lines, so that they can be zip tied to the frame if needed.

19) Control module power wiring

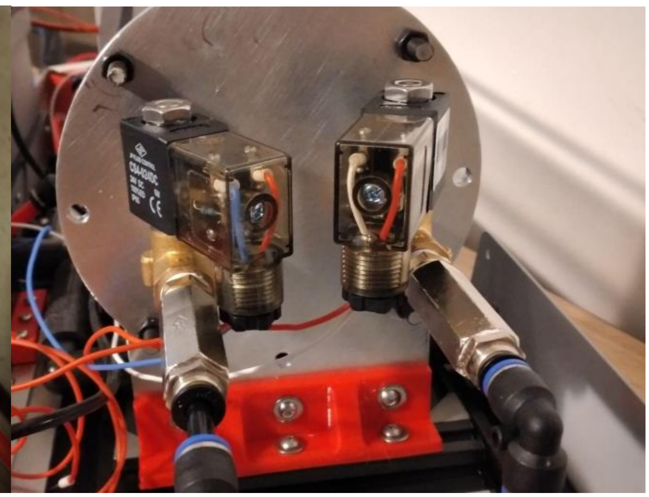
   On PolyVent machines, Red is used for 24V, black for GND, yellow for 5V, green for 3.3V. If you used a different color code on your machine, you must account for it. The backplane has labels for GND, 24V(PWR), 3.3V, and 5V. Once plugged in, add an ESP32 card to the backplane, with the microcontroller taken out. Plug in the machine power, and flip the ON switch. If a green LED turns on in the ESP32 card, then the wiring was done correctly, and the rest of the cards can be added safely.

20) Valves board wiring.

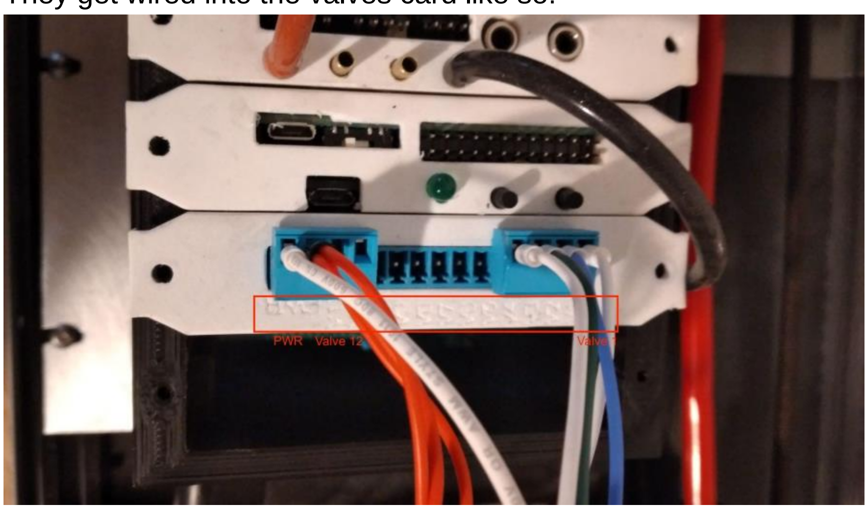
   The valves can be wired according to this diagram:



Wires must be added to the DIN connectors of the valves, like so:

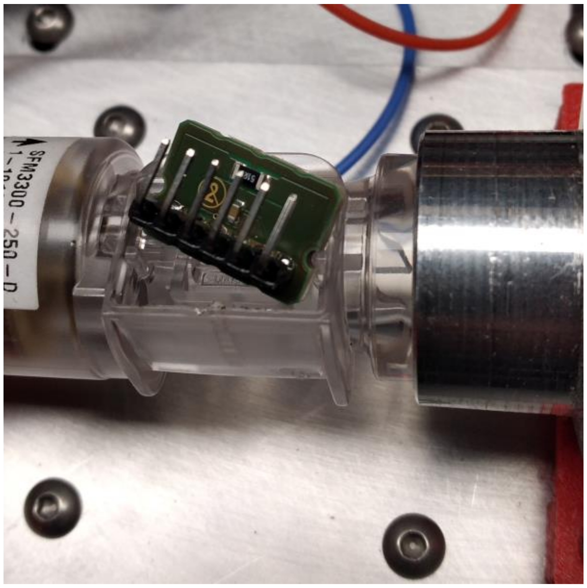



The blue wire represents an oxygen valve, and the white one an air valve.
They get wired into the valves card like so:

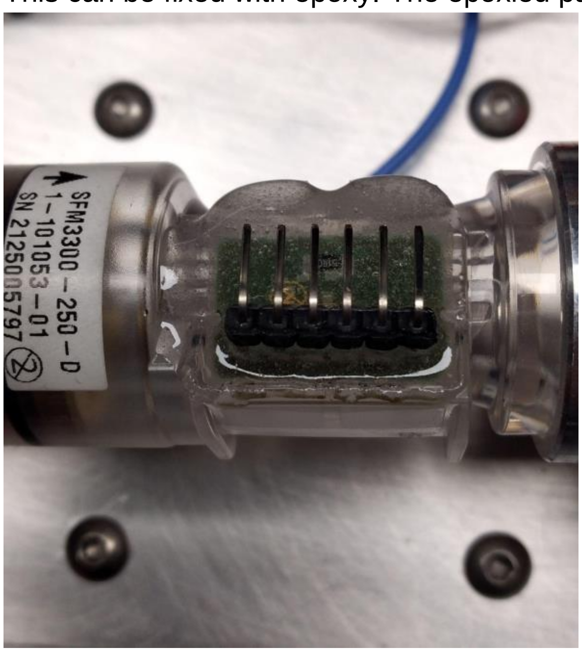


21) O2 sensor installation and wiring.
    The Oxygen sensor in the PolyVent has an 18 month shelf life, install only when it is ready for use. The oxygen sensor connects to the sensing card with a headphone jack. It is mounted in the sensing manifold, in the top M16*1mm thread.
22) Flow sensor wiring

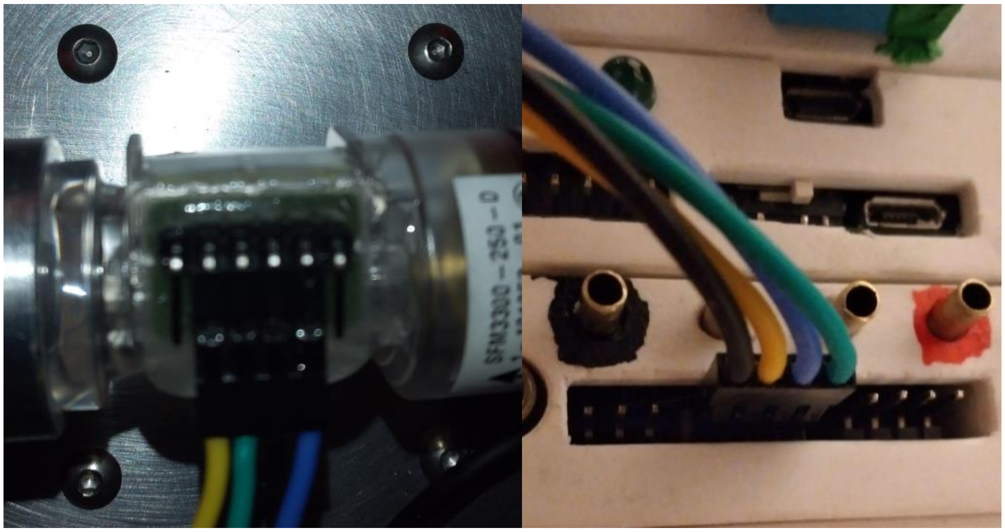
The flow sensor needs headers soldered to it. This is not ideal, but we have not been able to find clips for the sensor available anywhere. Sometimes, if too much heat is applied to the sensor during soldering, it comes off, like this:



This can be fixed with epoxy. The epoxied part looks like this:



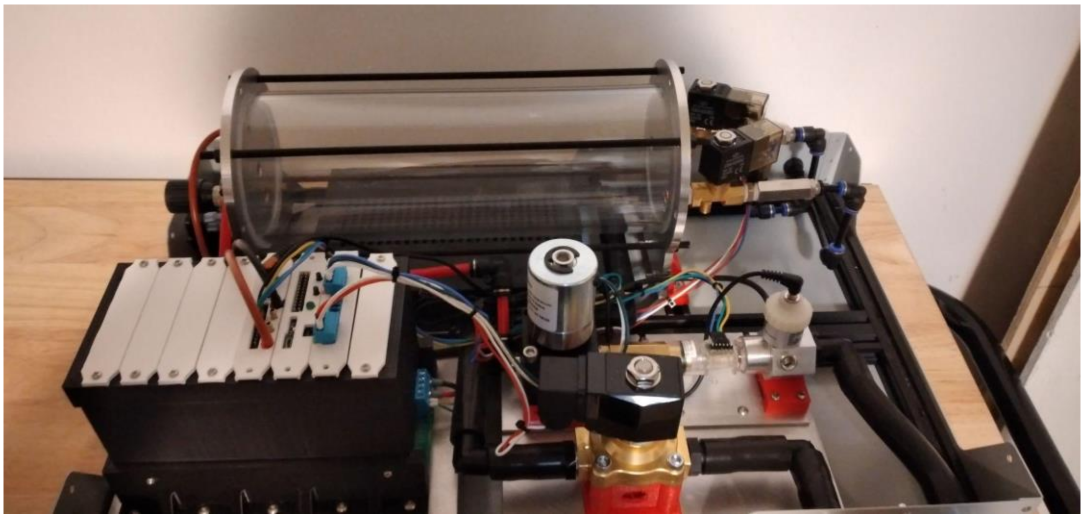
The wiring can then be added like this:



Make sure to wire it this way, and notice that the ends of the connector have different pinouts. This is necessary for the flow sensor to work properly.

23) Clean up the wiring and tubing

Zip tie the wiring to the frame, and label the connectors as needed. Add the blank covers to unused slots in the control module. My finalized wiring looks like this:



24) Finishing touches:

- Make sure the overpressure valve in the tank is set to 50 PSI.

- Add labels to the input and output couplers, like so:

25) bend case top
    This is by no means the best way do do this (ideally an industrial oven should be used).
26) glue case sides
27) Put case on top
28) All done!

Code and Smoke Testing

Install VentOS

Use a micro USB cable to load the most recent VentOS software onto the ESP32 by connecting it to the second micro USB slot on the control card (the one on the daughter board, not the main board. Follow the VentOS PlatformIO instructions for this. For example, you ay issue the command:

```
make pio-run-polyvent-pv
```

At this point, before installing the Valves Board itself in to the control module, you should be able to perform two tests:

1. Power the system on and see if you can smell or see “smoke”. This is called a “smoke test”, and although a bit humorous, it is useful.
2. Secondly, you should be able to see startup and at least some debugging messages on the serial port, either with a terminal program, the Arduino IDE, or the PlatformIO.
3. You should be able to send commands via the Serial Port to the VentOS running the ESP32, and get see acknowledgements of those commands. Please see VentOS repo for documentation on this.

Install the Valves Board Control Software

Valves board code: use a micro USB cable to upload the Valves Board Code, which can be found here: https://gitlab.com/polyvent/polyvent_control_module/-/blob/master/Boards%20CAD/valves_card/firmware/valves_control_board_code/valves_control_board_code.ino

The easiest way to do this is with the Arduino IDE.

Once this board is plugged in and connected, you are ready to perform an additional test.

1. When the PolyVent is powered on with the boards attached, you should be able to hear and feel the solenoids click about once every 10 seconds. The time will be changeable by sending the VentOS command to change the Breaths Per Minute parameter.

Starting the Machine with Pressure

At this point you should be ready to apply a small amount of pressure to the system. We recommend you use a tank of compressor set to about 15 psi (less than the 50 psi it is rated for) for initial testing. It is easiest to test without pressurized Oxygen at first, by simply using pressured air in both the air and O2 inlets.

1. With the system running but not attached to a test lung, slowly increase the input pressure. You should be able to feel a puff of air coming out of the “inspiration” port. Because the system will not be able to produce pressure with no test lung attached, the proportional valve may vibrate unpleasantly.
2. Shut down the machine and attach a breathing circuit and test lung. Ideally the breathing circuit should have a pressure release pop-off valve, which should be set of 60-80 cm H2O pressure.
3. Now turn the machine back on, and stand back, as a hose or test lung may pop loose. The system should pressurize the test lung and then allow air to escape out of the test lung through the expiration port and through the exhaust port in the back of the machine.
4. If the machine is rhythmically filling the test lung and not overfilling it, then you can begin experimenting with sending commands to change the PIP, breathing rate, and Inhalation to Exhalation ratio as defined by the VentOS documentation.
5. WARNING: If the test lung overfills, please make sure that the thin hose from the port of the pressure sensor on the valve card is properly connected. If this is not connected, the PolyVent cannot successfully regulate pressure and will overfill the test lung. Usually, a hose will pop loose, but the test lung itself could explode in this situation.

An Overview of the Software Operation

For complete information, please see the VentOS documentation. In a nutshell, the VentOS runs a “superloop” or “simple loop” architecture with an explicit task manager.

One of the tasks is to listen on the serial port for commands. The other task is to control the machine itself. The solenoid valves are controlled by a second board, which is communicated with via SPI communication in the backplane of the control module.

The main control loop reads the pressure and adjusts the proportional solenoid valve to be slightly more open or slightly more closed to maintain a steady target pressure. This is internally controlled with a PID controller. When the inhalation phase is over, the PIV valve opens.

VentOS has considerable internal debugging features, but they are only usable by an experienced C++/Arduino programmer. If you become stuck, please contact Public Invention for free technical support.

Troubleshooting and Common Problems

This section may have to be expanded over time.