Automated Vacuum System

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Abstract:

In this project, the goal was to build and automate a vacuum system that could get down to very low pressures while being automated to run its safety features, powering the pumps, and transfer data all on its own. To achieve this goal, we were given a whole collection of vacuum hardware and were allowed to use Arduino hardware to program the system.

In the end, we were able to create a self-running vacuum system that could turn on the pumps, transfer data, and perform its safety procedures, but we did get just a bit shy of the pressure we wanted to get to.

Introduction:

There is a multitude of hardware that is needed to create a vacuum system. This hardware includes a scroll pump, turbo pump, Hornet/ion gauge, worker bees, O-rings, clamps, and a chamber.

A scroll pump is used as a backing pump for the turbo pump and what it does is it brings down the initial pressure (atmosphere) to a safe value that allows for the turbo pump to be turned on. We worked with a rotary vane pump which would be capable of bringing a sealed system down to a pressure of 1.5e-2 Torr but can't get the pressure any lower than that. Unlike the scroll pump, could only be used at lower pressures and is capable of bringing the pressure of a sealed system down to e-5 Torr. While the turbo pump runs it uses the scroll pump as a backing pump.

A Hornet and worker bees are used to measure the pressures of the system. How they work is the worker bees get connected to the parts of the chamber where you want to measure pressure while the hornet is connected to the main part of the chamber. They transfer the data to the Hornet which displays the pressures. The worker bees are accurate until the pressure gets

very low around e-3 Torr and that's around when the Hornet turns on the ion gauge which is used to measure very low pressures. The Hornet is also capable of transferring small voltages to an outside source to relay the pressure information.

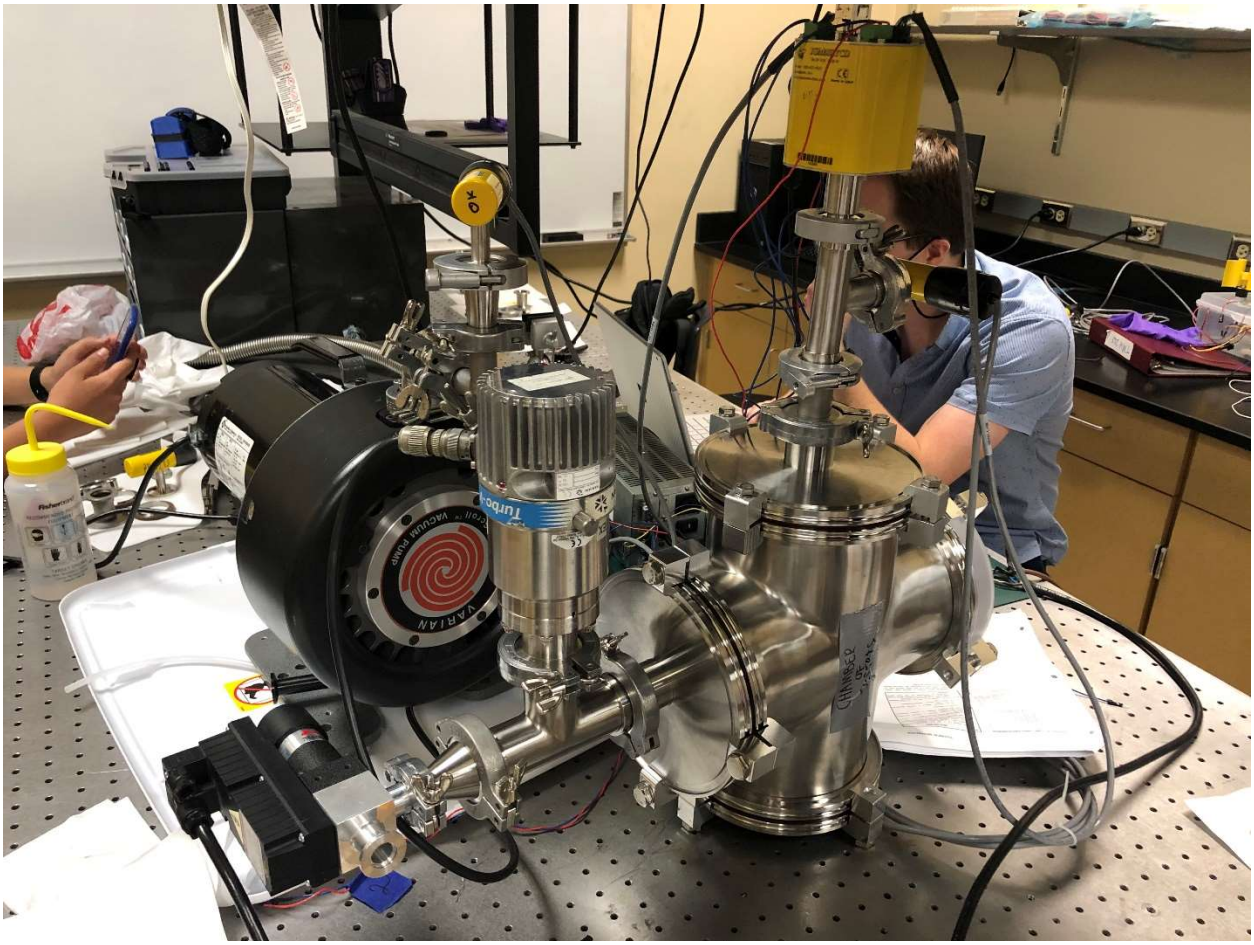
When building a vacuum chamber, o-rings are used as a median of connection from object to object. Once connected, clamps fasten and maintain the connection. The rubber ring that the o-rings have allow for a tighter seal which prevents leaks from coming out of the chamber.

When working with a vacuum system there are many protocols that have to be followed. To begin with, all of the internal hardware has to be cleaned because dirty hardware leads to more leaks which can alter the values you get for pressure. Using gloves is necessary so that the oils or debris from your body doesn't get into the system. For the safety protocols there are the following: don't turn on the Turbo before it gets to a low enough pressure, always keep the scroll pump backing the turbo, even when you turn off the turbo keep the scroll pump on, if it doesn't reach a low enough pressure after some time the turbo pump system had to begin to turn off, and the shutoff valve can only be released at some higher pressure.

Methods:

Structure: Building the structure for the vacuum system was quite simple. The major components we needed to have was that the turbo pump, scroll pump, hornet, valve, and two workers bees and to be connected in series with the main chamber. On top of the main chamber, we had a worker bee along with the hornet. This would allow for the pressure to be read from the main chamber at any pressure. Connected to the side of the main chamber was the turbo pump and shutoff valve both on a "T" connection. Because the turbo and scroll had to be connected in

series specifically with the scroll coming after the turbo pump, we had the scroll pump connected directly to the turbo pump with a worker bee in the middle so that the pressure in the turbo could be read.



In this image you can see how we setup the vacuum system. The main chamber is the big cross that is standing on the table. On top of the chamber, you have one worker bee and the Hornet and to the left you see the turbo pump standing vertically with the valve to the side. The scroll pump is also connected in series to another worker bee and turbo.

Wiring: The wiring was quite a bit complicated. To begin with, since Arduino hardware can't receive input values of any voltages greater than 5V, we had to make multiple voltage

dividers since the Hornet output values higher than 5V for its pressure readings. We made three voltage dividers, one for each worker bee and another for the ion gauge. Since the pumps and shutoff valve had to be turned on automatically and not by hand, we had a connection to the wall that would supply power to the scroll pump whenever one relay was open and another to the shutoff valve whenever its relay was open. Because the turbo pump used smaller voltage values around 25V and the wall supplied 120V, we connected a relay to a power generator and had that connected to the control panel for the turbo.

In this image you can see the relays that are all connected to the Arduino and the voltage dividers on the breadboard. Some of the wires from the Arduino connect to the control panel for the turbo pump and some can be seen extending vertically to the worker bee and Hornet.

Code: We setup our code to run the following functions. By initializing the code, we had it begin with opening up the relay that would power the scroll pump. With the function to read the pressure that the Hornet outputted, we were able to setup the turbo pump to turn on at a

certain value by opening the relay that was connected to the control panel. From here, if the system didn't reach a low enough pressure or once it reached the desired pressure, we setup a command to begin the shutoff process by having a timer in our code. During the shutoff process, our code was setup to close the relay supplying power to the turbo pump and once it received an input value for a safe enough pressure for the scroll pump to turn off then the shutoff valve would open and the scroll would turn off at the same time. The code that we made was setup to run the vacuum system on its own once it was turned on and display the date it received.

```
    if (CG1Pressure < 500 && CG2Pressure < 500) {
      digitalWrite(turboPin, HIGH);
      Serial.println("Turbo Pump Is On");
    }
    if (timer > 3*pow(10, 5) && hornetPressure > 700) {
      digitalWrite(turboPin, LOW);
      delay(1000);
      i = 1;
    }
  }
}

while (i=1) {
  timer = millis();
  int a = 0;
  if (a=0) {
    timer = 0;
    nextAct = millis() + WAIT;
    a = 1;
  }
  float CG1Value = analogRead(CG1Pin) * 2;
  float CG1Voltage = 5 * (CG1Value / 1024.0);
  float CG1Pressure = pow(10, (CG1Voltage - 3));
  Serial.print("CG1 = ");
  Serial.print(CG1Pressure);
  Serial.println(" millitorr");
  delay(1000);
  if (timer >= nextAct) {
    digitalWrite(scrollPin, LOW);
  }
  if (timer >= nextAct*2) {
    digitalWrite(valvePin, HIGH);
  }
}
```

Here is part of the code that we wrote. At the top you see functions that will tell the turbo pump to either turn on once it gets to a low enough pressure or the safety feature to turn off if it takes too long before dropping to an ideal pressure. At the bottom we have our functions to read and display the pressure that is being inputted into the Arduino.

Results:

```
Hornet = 100000.00 microtorr
CG1 = 390.30 millitorr
CG2 = 291.29 millitorr
Time = 0 minutes
Turbo Pump Is On
```

This is the data when the turbo turns on.

```
Hornet = 411.96 microtorr
CG1 = 1.47 millitorr
CG2 = 47.05 millitorr
Time = 0 minutes
Turbo Pump Is On
```

This is the data when the Ion gauge turns on.

```
Hornet = 45.38 microtorr
CG1 = 0.94 millitorr
CG2 = 29.99 millitorr
Time = 7 minutes
Turbo Pump Is On
```

This is the data that was read when the pressure started to plateau.

```
Hornet = 40.55 microtorr
CG1 = 0.96 millitorr
CG2 = 29.99 millitorr
Time = 11 minutes
Turbo Pump Is On
```

This is the data for the nearly the lowest pressure we could get to.

Discussion:

In the set of yellow highlighted data, it displays the pressure values and time at which the turbo pump turned on. You can see that we had the turbo setup to turn on at a value of 2.91e-1 Torr and it took less than a minute to get there. The scroll pump was supposed to be able to reach a value of e-2 Torr, but we would wait a long time before getting close enough to e-2Torr with just the scroll pump so we had to have the turbo turn on a bit before.

In the set of green highlighted data, it displays the value at which the Ion Gauge turned on. You can see that at a value of 1.4e-3 the ion gauge would be on. On the same data you can notice how CG2 worker bee is outputting a much larger value of pressure, this is no mistake, since the worker bee was connected between the turbo and scroll, there would be air running through there as it's pushed out so the pressure on CG2 was expected to be higher.

The set of blue highlighted data indicates the pressure value where our system started to stagnate at. At a pressure of 4.5e-4 Torr, we started to see a stagnation in our value for pressure. At this point, it started to take a very long time for the pressure to drop units. As you see in the data highlighted in purple, it dropped .5e-4 Torr before it stopped dropping in pressure and it took an extra 4 minutes from 4.5e-4 Torr.

The reason we couldn't get down to our desired pressure was because there were some small leaks in our system. We had a lot of connections in our vacuum system, when you have a lot of connections, the chances of having a small leak somewhere increases a lot. We assured to clean the chamber multiple times especially before our final run where we collected data, but the

chamber can't be 100% clean so the miniscule amount of debris could've caused small leaks too. We were also working with very old hardware which could've had some effect on our pressure values.

Conclusion:

In the end, we were able to automate a vacuum system with built in safety features that could get down to 4e-4 Torr. Our system ran very well and we had no problems with the automated features, but we came up just a tad bit short from our goal of e-5 Torr. It was interesting to learn about the features of a vacuum system hands on. For next time, with newer equipment or less connections in our system, we could possibly get to a lower pressure value.