DigiVac

Scientific Measurement & Control

ENHANCING SPACE RESEARCH EFFICIENCY:

VACUUM SYSTEM TO MITIGATE REGOLITH INGESTION

By DigiVac

Presented by Tim Collins

Objectives

01 Introduction

02 Research Context

03 System Development

04 Testing & Troubleshooting

05 Results

The Problem

How do you get to high vacuum without disrupting Regolith?

There is a lack of efficient and automatic systems that could execute a controlled evacuation that would minimize the movement of moon dust or fine particles for In-Situ Resource Utilization (ISRU) to expand upon lunar exploration.

Customer inquiry

How do you get to high vacuum without disrupting Regolith?

Requirement: To achieve 10^{-5} Torr without moving Regolith. To achieve vacuum ramp from 20 - 1 Torr.

System Abilities:

- Vacuum range: ATM to 10^{-6} Torr
- Vacuum controller with Automation, cycles/ recipes, and digital readout
- Simple to use
- Graphing capabilities
- Easy to move | a preference for a neat, compact, and moveable system given limited lab space.

NOTE: The system will be used by novice vacuum users; make it difficult to break

To Consider:

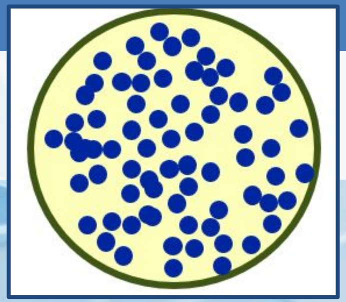
- Should regolith get ingested by a vacuum system, a pump's lifespan is shortened and experimental media is destroyed

Understanding Vacuum

Defining Vacuum Regimes & Importance of Viscous & Molecular Flow

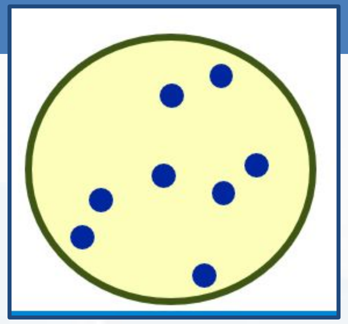
Viscous Flow

- Distance between Molecules is small
- Collisions between Molecules dominate
- Flow through momentum transfer
- Generally P> 100 Millitorr



Molecular Flow

- Distance between Molecules is large
- Collisions between Molecules and Wall dominate
- Flow through random motion
- Generally P< 1 Millitorr



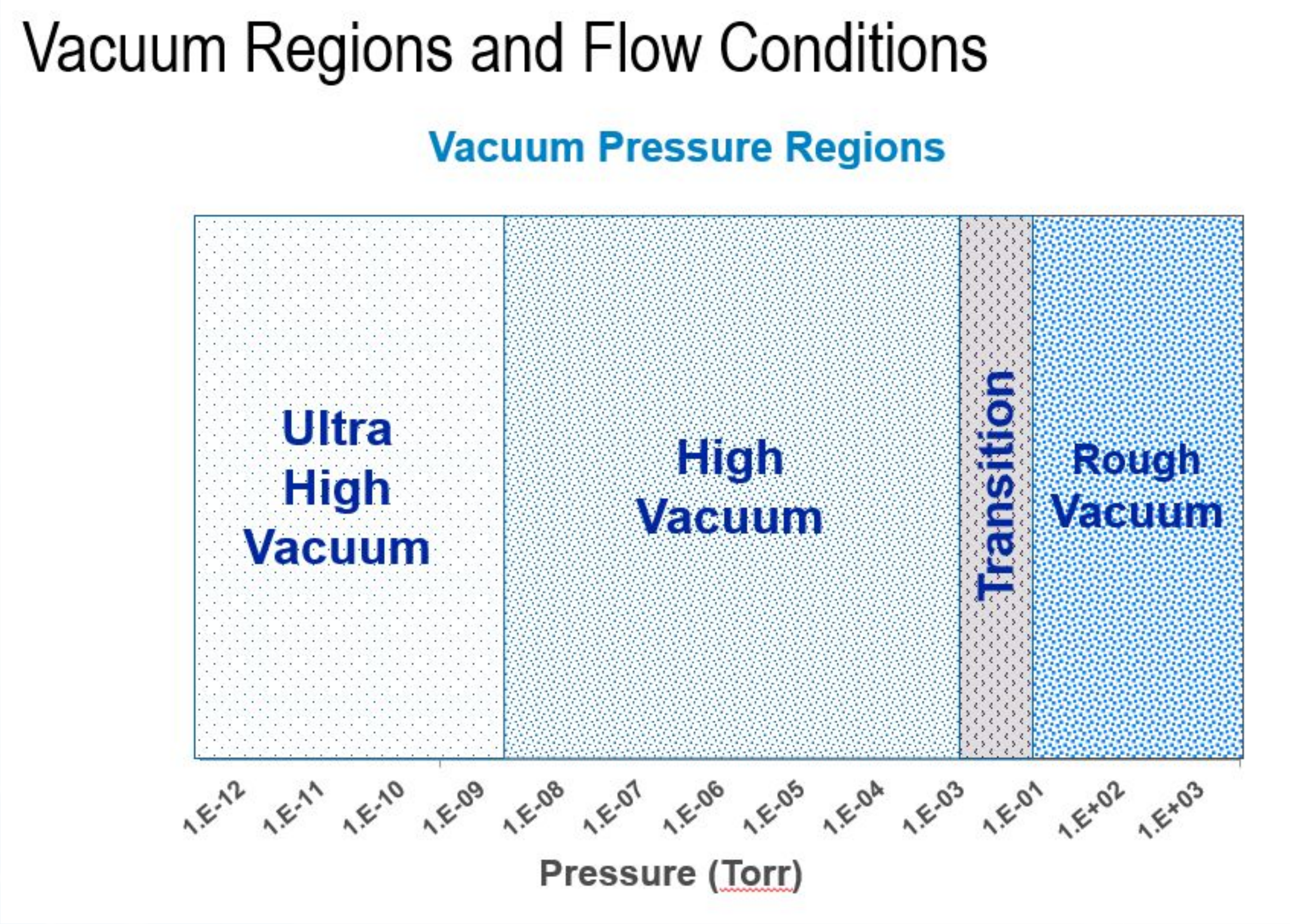
Transition Flow

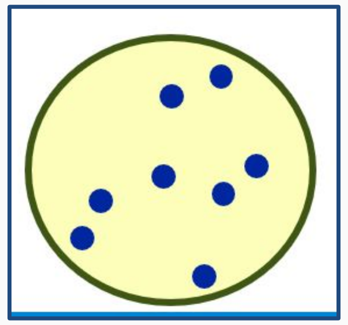
Region between Viscous and Molecular Flow

Agilent Technologies
Contributed by: Agilent Technologies

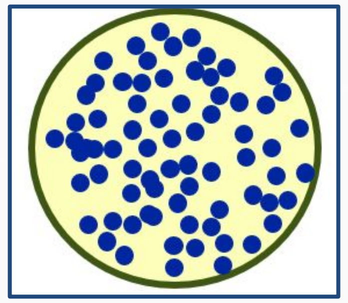
Why Do We Care?

This System needs both a rough and a high vacuum system





Turbo Pump = Molecular



Rough Pump = Viscous)

NASA Research | SUMMARY

Development and Testing of an ISRU Soil Mechanics Vacuum Test Facility

Early vacuum testing has shown that this gas release can occur violently, which loosens and weakens the simulant, altering the consolidation state.

TEST METHODS:

- A mid-size chamber (3.66 m tall, 1.5 m inner diameter)
- A 0.64 m deep by 0.914 m square metric ton bed of lunar simulant
- Both GRC-3 and LHT-3M simulant types were used.

FINDINGS:

Simulant disruptions, caused by off-gassing, affected the strength properties, but could be mitigated by reducing pump rate.

RESULTS:

No disruptions were observed at pressures below 2.5 Torr, regardless of the pump rate. The slow off-gassing of the soil at low pressure lead to long test times; a full week to reach 10–5 Torr.

DigiVac | Our Experience

01 Develop and Engineer Vacuum Measurement and Control Solutions well established gauge, controller and automated system portfolio

02 Work in Rough, Medium and High Vacuum Applications: Ranging from Medical, Pharma, Industrial, and R&D including Space Research.

03 Prior Experience in Space Field: TVAC, High Vacuum Gauges and Systems, Methods and Tools for Drying Fine Powders.

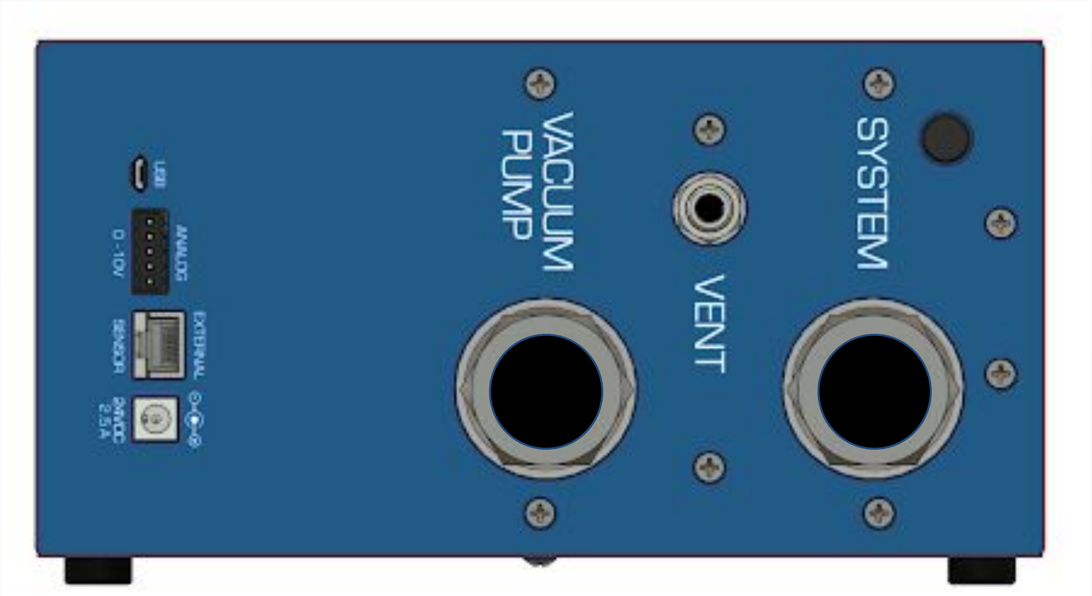
04 Recent Development of custom valve technology to address rough and medium vacuum control leveraging high vacuum design

Developed Technology

2020 Developed Patent Dual Proportional Valve Technology

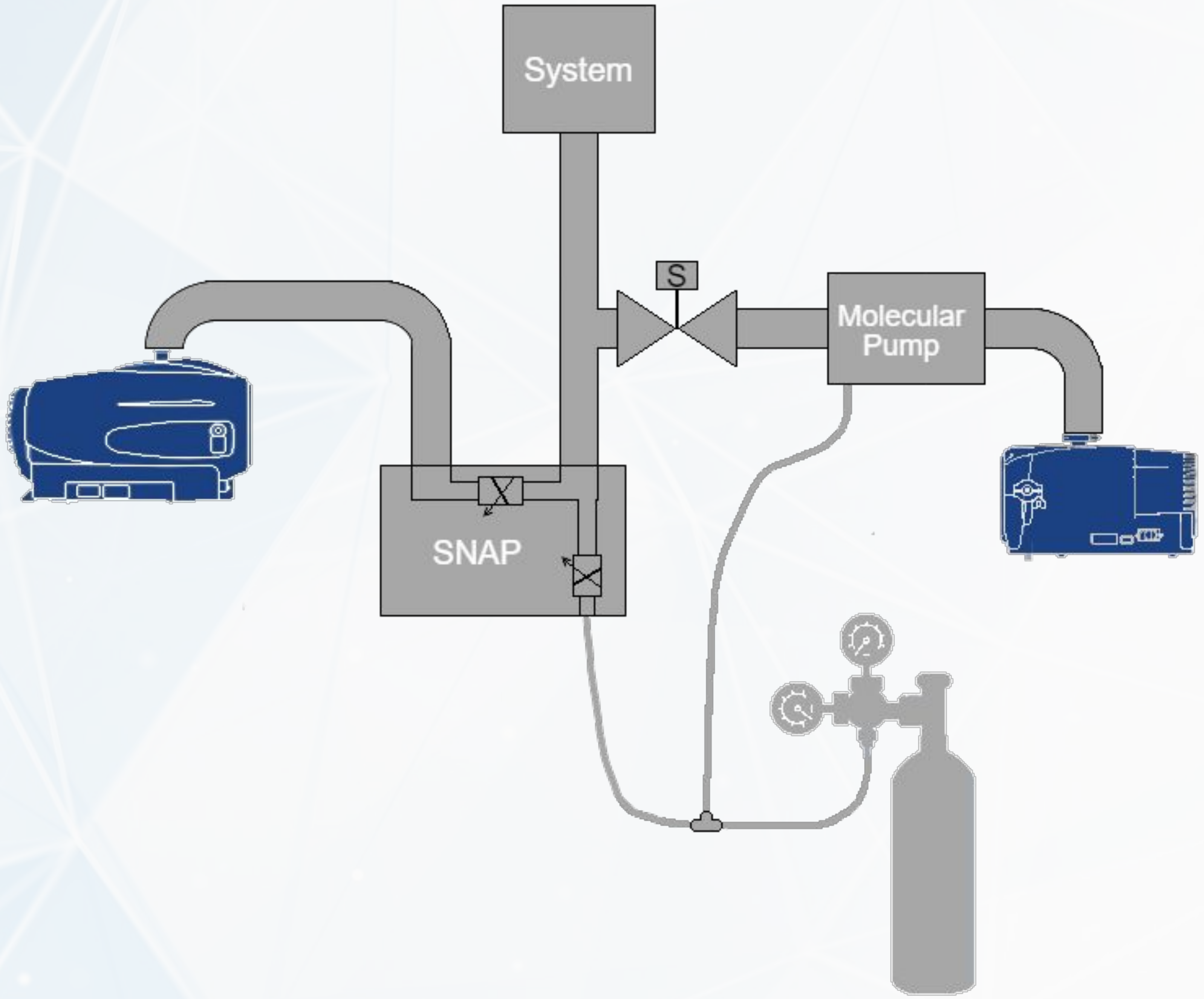
SNAP

- **Defined:** high flow, process controller has the ability to automate evacuation and purge cycles for easy control of your vacuum process.
- **Operation:** with the use of Proportional throttle and proportional bleed control (vent to atmosphere) delivered from an integral dual valve module per channel allows precise control and venting in one, with the touch of a button or the twist of a knob.



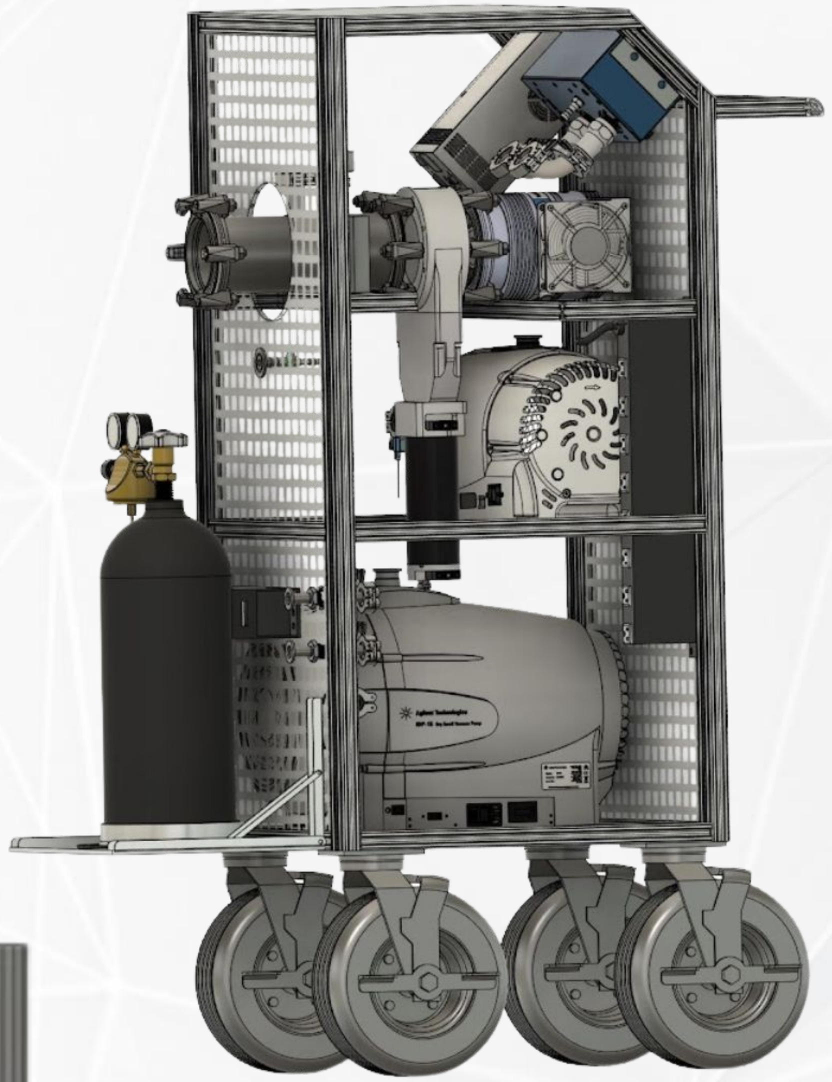
System Development

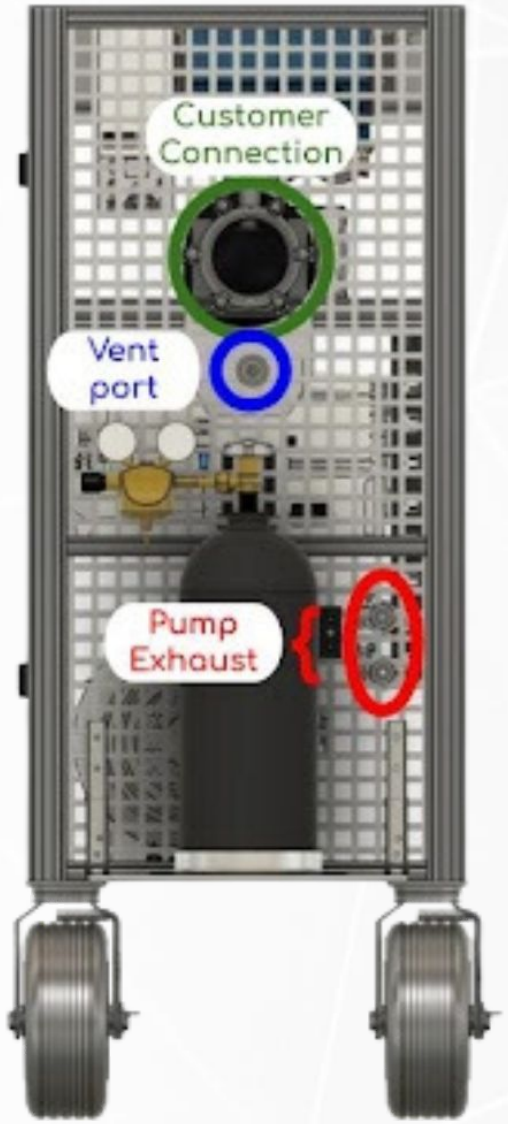
Solution Configuration



System included:

- Custom Cart
- Valves
- Snap Vacuum Controls
- Pumps
- Sensors/ Gauging
- Specialized software
- Vacuum hardware




Customer Connection
Vent port
Pump Exhaust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System Development

System Requirements Mapped to the Provided SOLUTION

Vacuum Range
- Pumps
- Valves
- Sensors and Gauging

Vacuum Controller
- SNAP

Graphing
- SNAP
- Custom Software
- Sensors and Gauging

Automation
- SNAP Software
- Custom Software

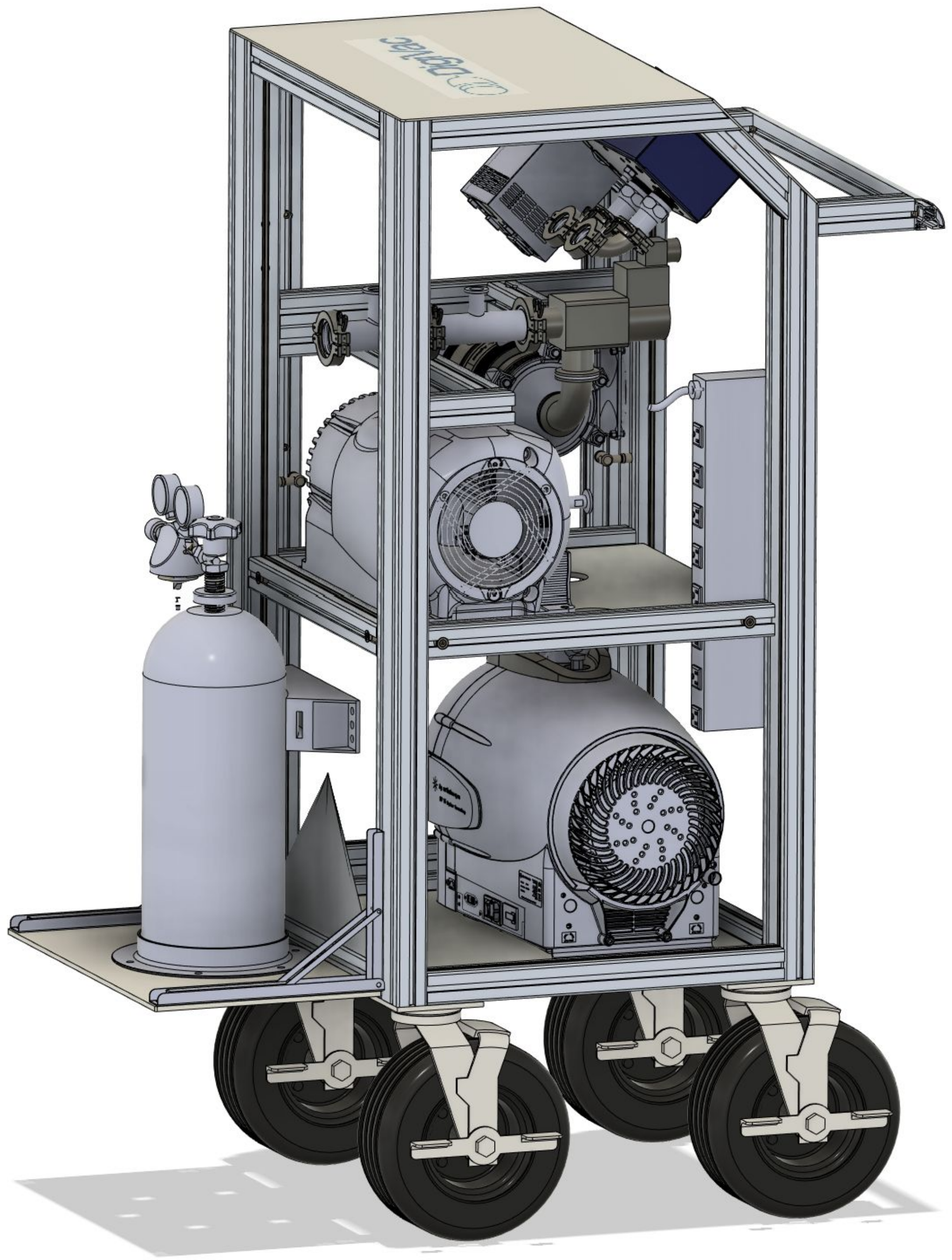
Cycle/ Recipes
- SNAP
- Valves
- Sensors

Easy to Move
- Mobile Cart
- Vacuum Hardware

Simple
- SNAP Interface
- SNAP Software

Measurement
- Sensors and Gauging

KEY
System Requirements
PROVIDED SOLUTION



Development to SNAP

Originally, the SNAP only had the ability to control one vacuum valve, which allowed a user to control the pressure from one pump.

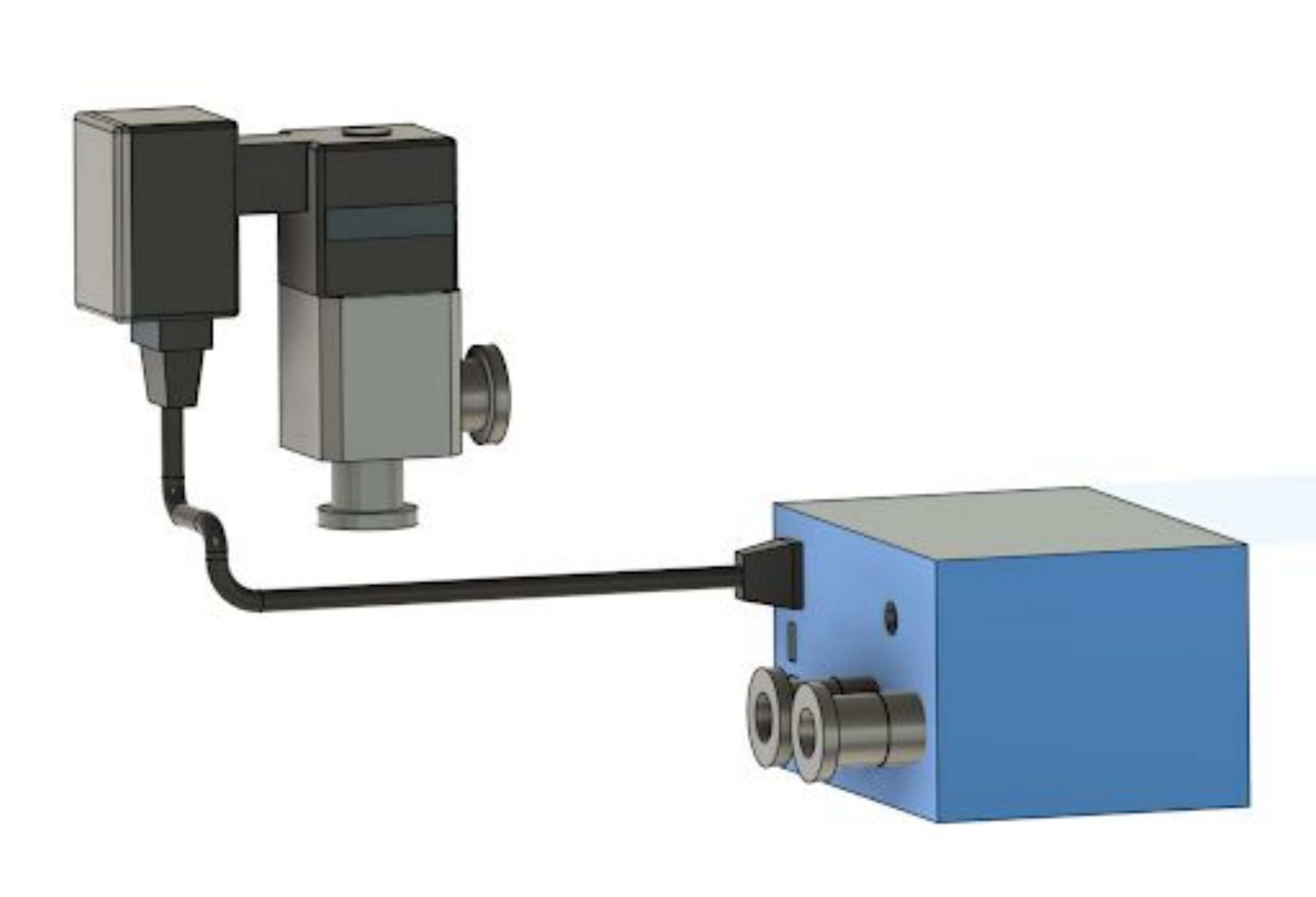
With this system we needed to take a step further with the need to pass from the rough pumping stage to the turbomolecular pumping stage, the internal SNAP valves have to close and the external valve opens.

To do this, We added additional features to the SNAP:

- **External Valve**
- **Hysteresis for the Valves**
- **Updated User Interface for a more Streamlined Control Paradigm**

External Valve

Development to SNAP



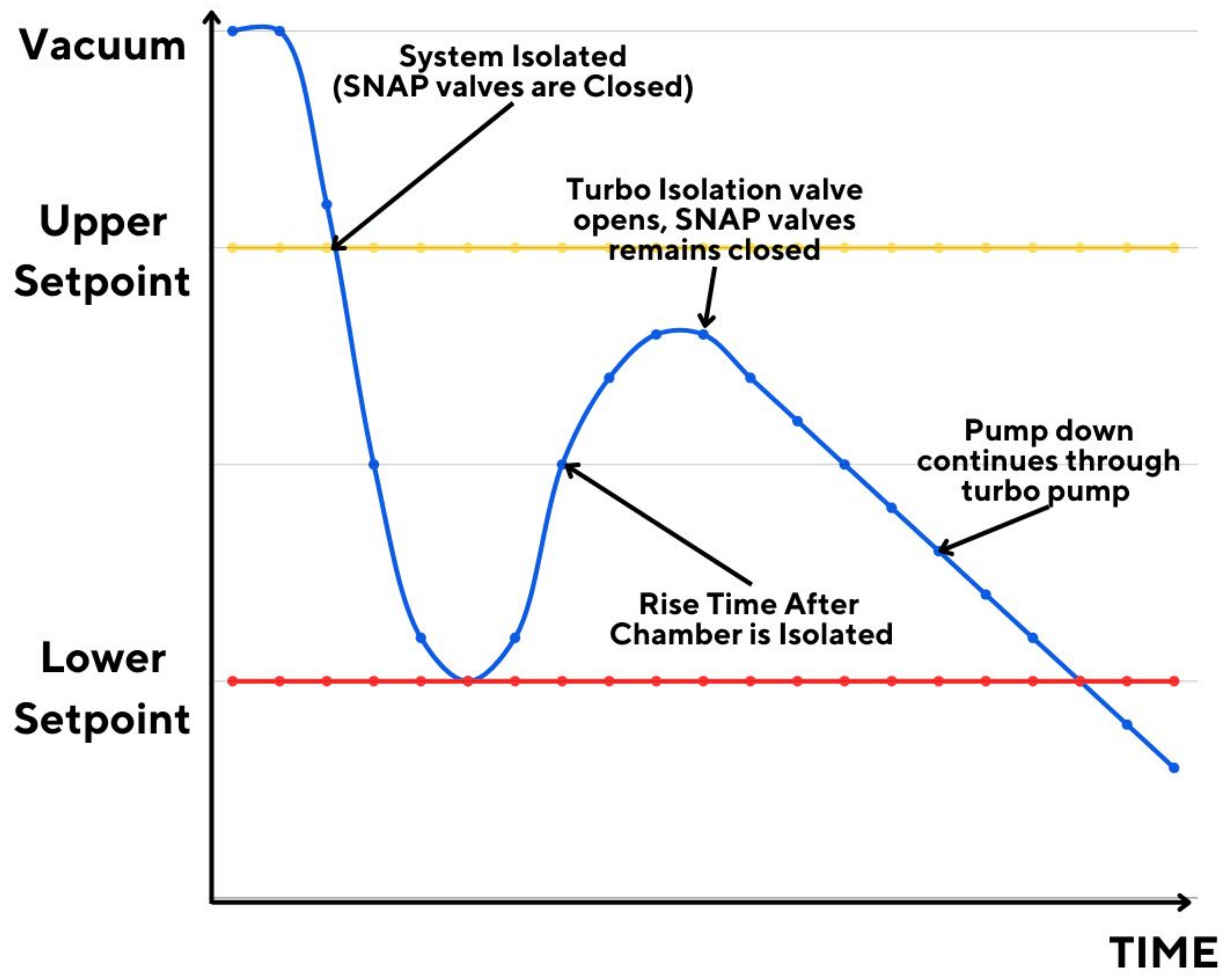
System Development

An external valve was added to give the SNAP the ability to isolate the turbomolecular pump from the rest of the system during the lengthy rough pump-down phases

System Development

Hysteresis for the Valves

Development to SNAP



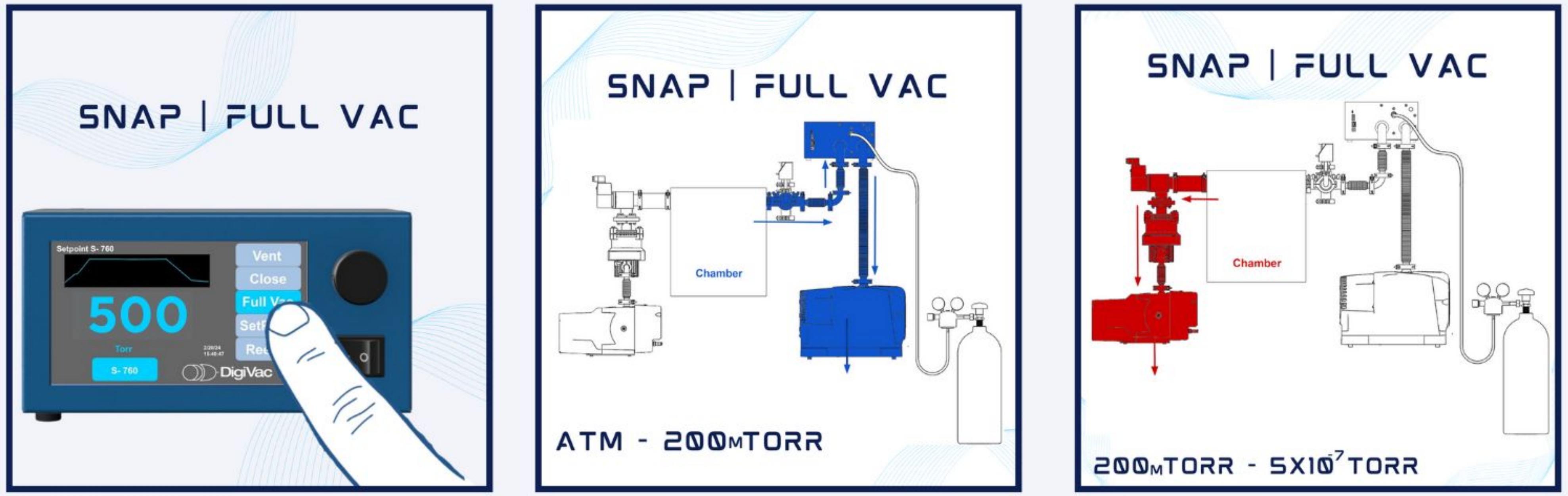
Hysteresis is Dependent on Vessel size, Outgassing and Leaks

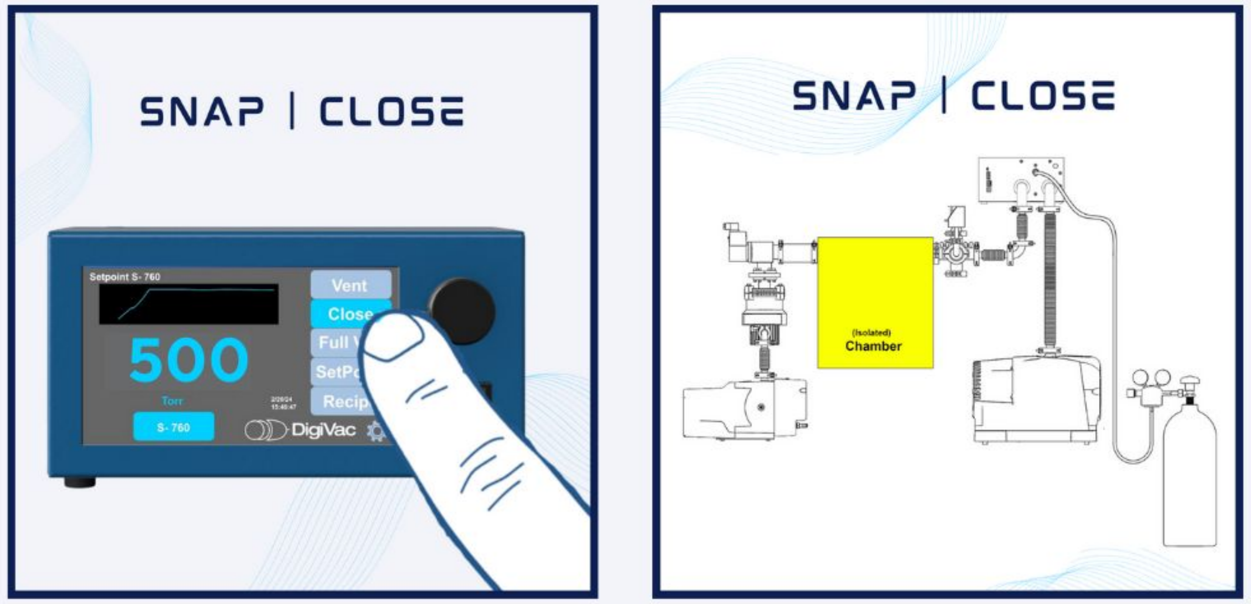
We had to include a hysteresis in opening the external valve due to the dynamic aspects of large vessels. We calculated the hysteresis we could allow while still ensuring the safe operation of the turbomolecular pump.

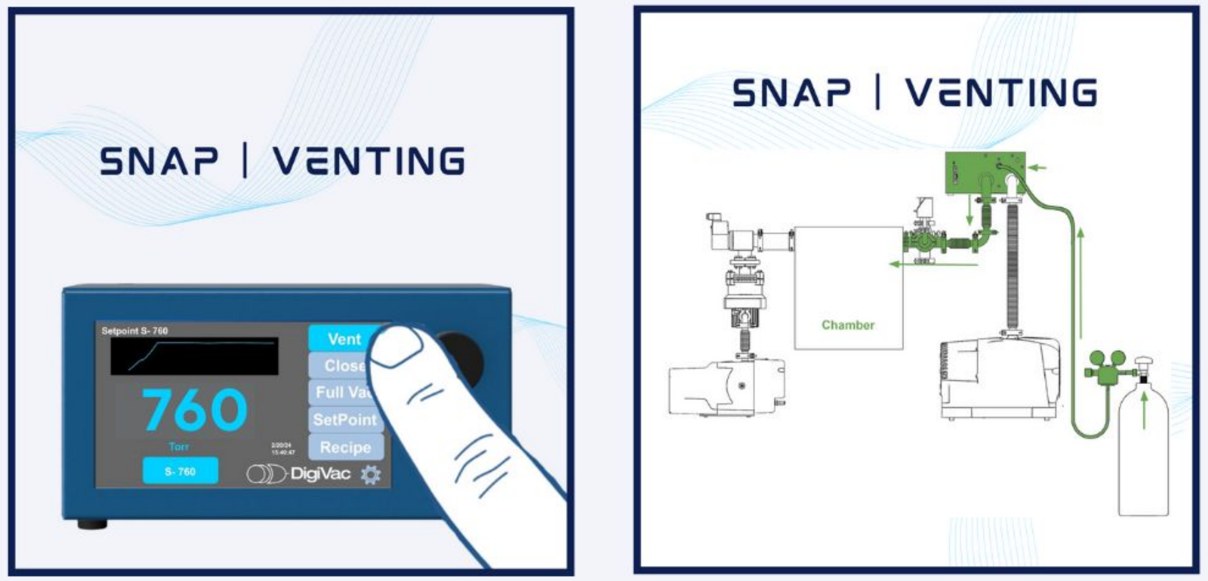
Updated User Interface for a more Streamlined Control Paradigm

Development to SNAP

- When **“Close”** is pressed, all valves are closed.
- Added new functionality to the **“Full Vac” button**. When pressed the system does a full evacuation, roughs the chamber and then closes the rough valve and opens the turbomolecular pump valve.
- When **“Vent”** is pressed, the vacuum valve and external valve will close, and the vent valve will open, venting the system with a clean gas, bringing system pressure to the atmosphere.
- On the **home screen,** user-friendly additions were made, such as a graphic showing that the external valve is “open” and the value of the high vacuum threshold.







System Performance Test

GOALS

- To achieve 10-5 Torr without moving dust.
- Achieve Vacuum ramp from 20 - 1 torr

System Configuration and Developed Technology

- High Vacuum System
- SNAP Controller
  - External Valve
  - Hesterias
  - Interface

- Testing was done continuously utilizing parameters provided by the client and referenced knowledge on what level of vacuum evacuation avoided disturbing fine particles (ref. 1).
- These tests were run with the SNAP vacuum controller and the utilization of an external valve, connected to the vacuum pumps that would make up the rest of the system.
- These tests were also run utilizing clean, dry bottled Nitrogen as a backfill source, with exhaust ports on the back of the cart allowing for the capture of said gasses. This was to test and ensure that there would be no ingress of contaminants.

Testing Begins

Test Setup

The SNAP, on a small vessel, was able to work for about 24 hours going in and out of all the modes with recipes, spanning about 20 hours. The same SNAP was then moved to the vacuum system cart where it exhibited interesting behavior.

Figure 3A. - A run from 1 Torr to 10 Torr back to 1 Torr. Ramps successful using set recipes.

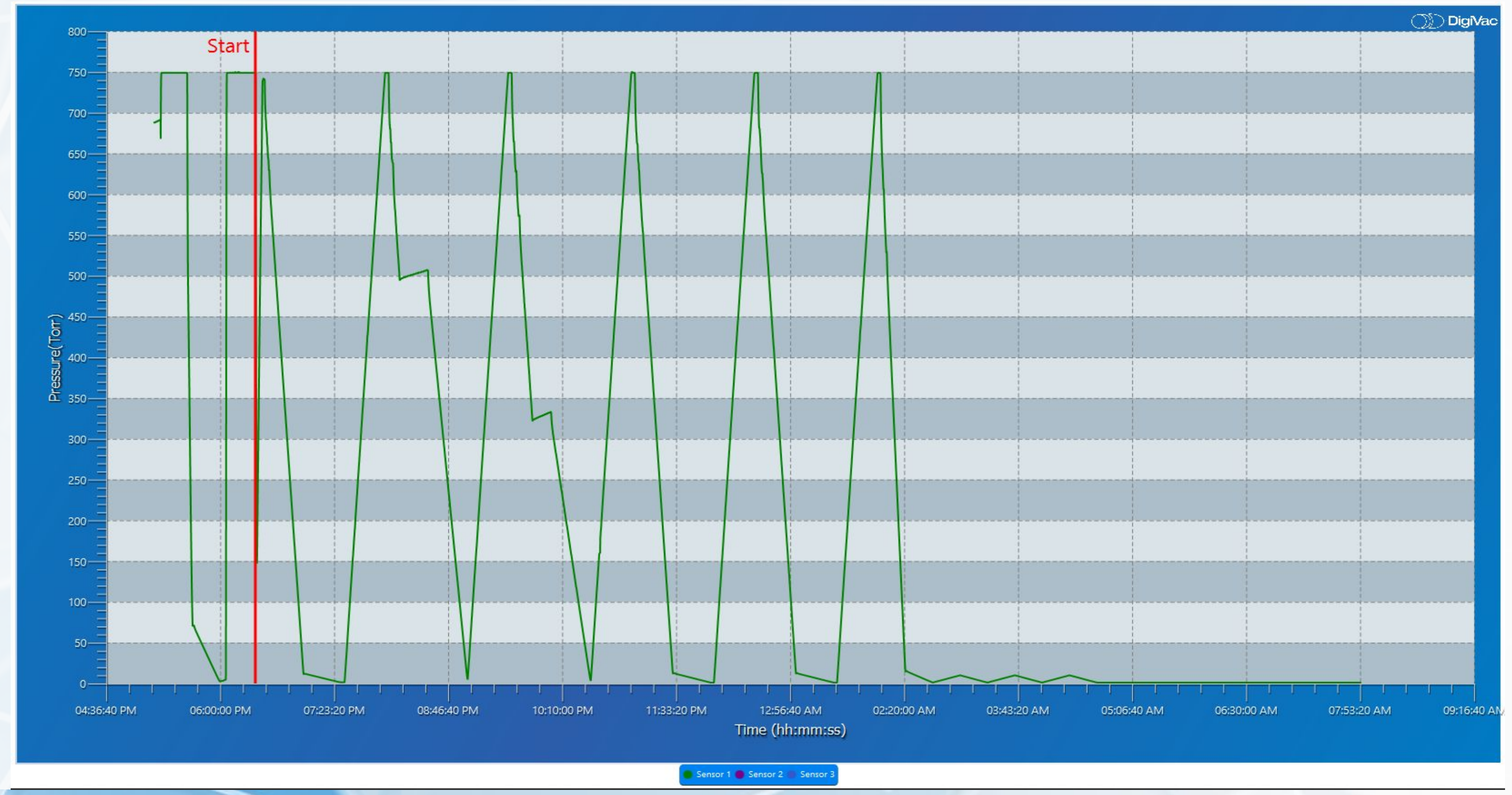
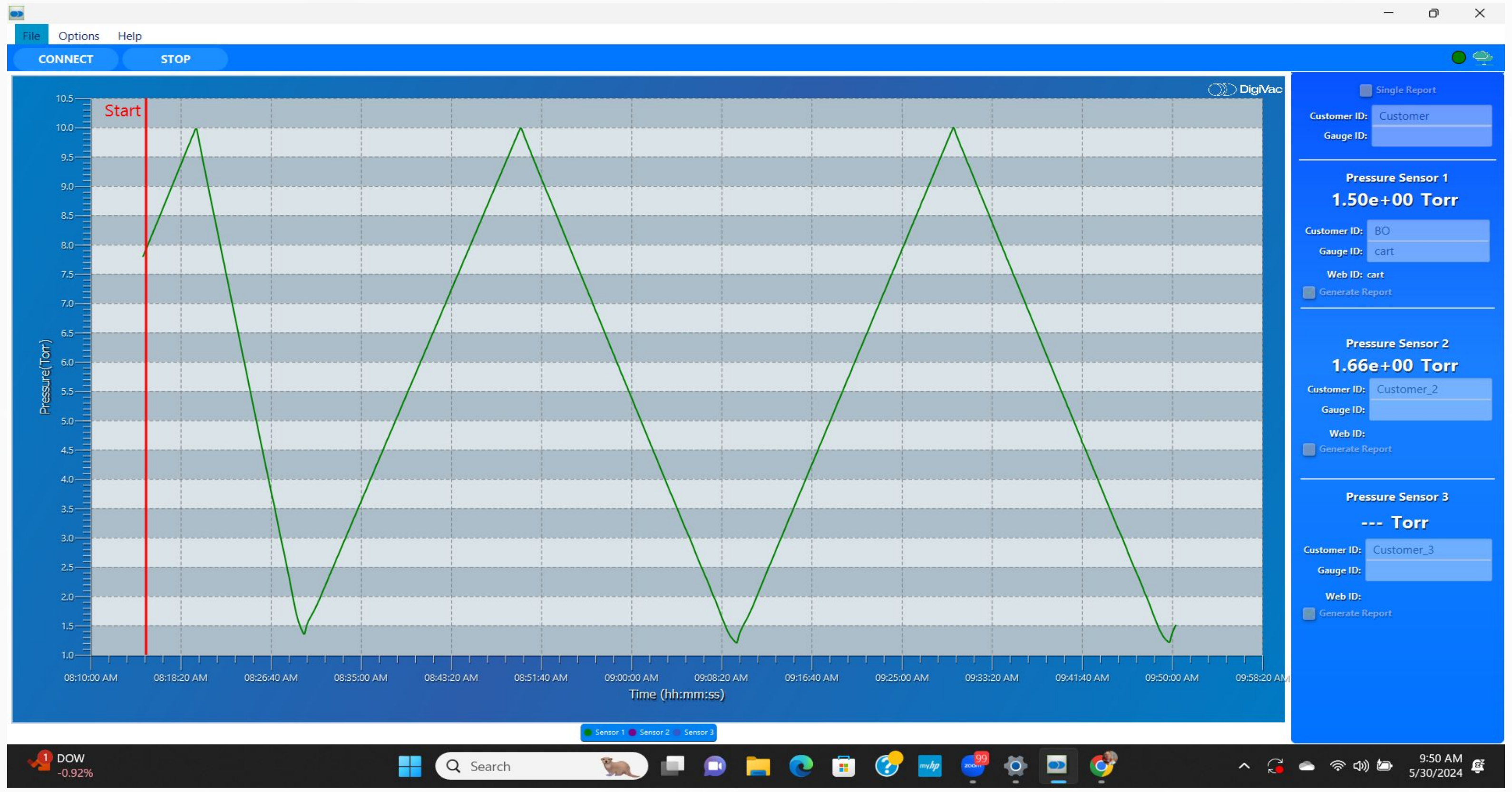


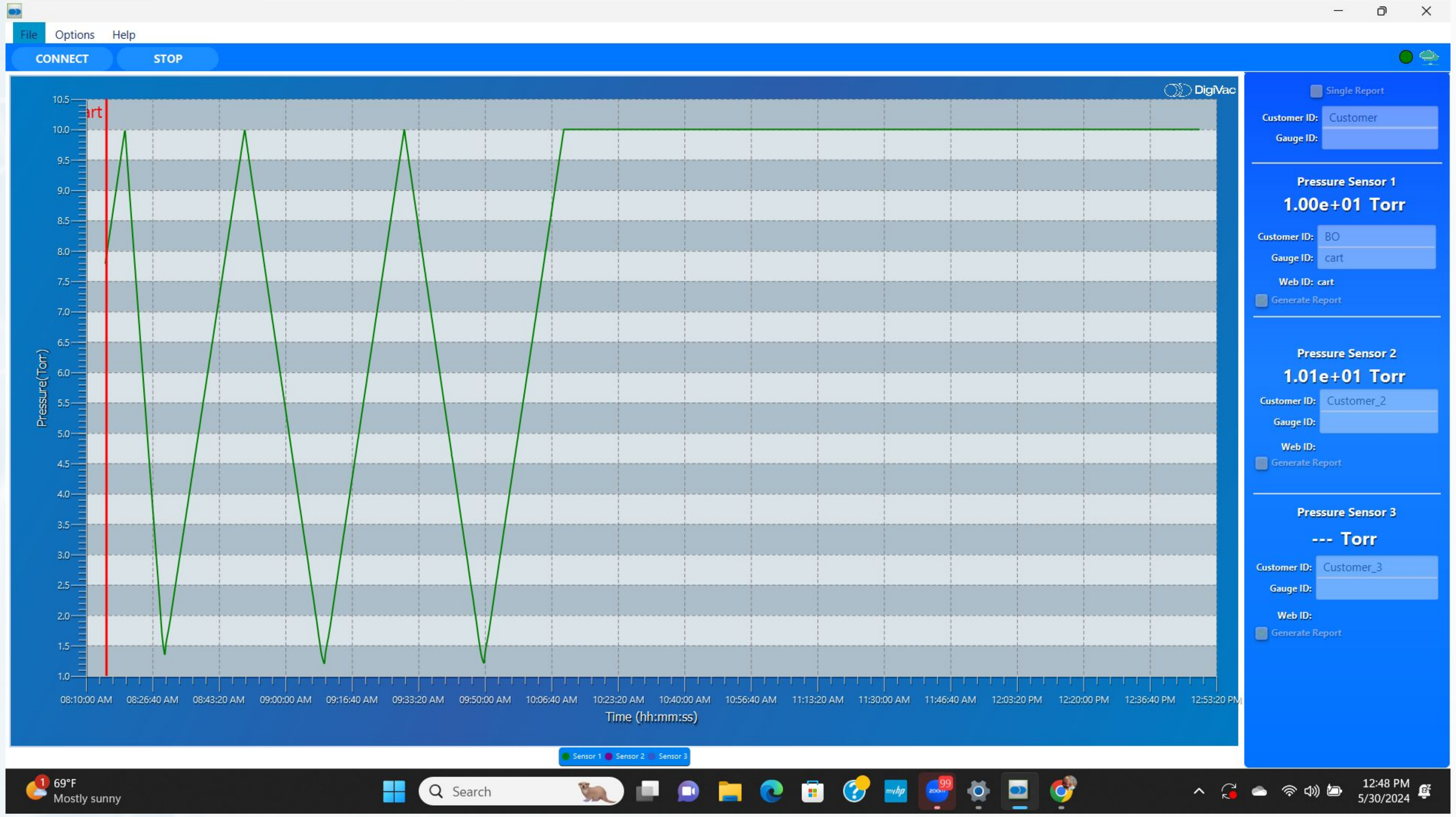
Figure 3B. - Exclusively testing 1-10-1 Torr ramps via set recipes. This graph displays the ramping during Recipe 7.



Testing & Troubleshooting

Bugs Found

Figure 3C. - A bug was encountered upon activating the external valve.



- **Issue:** when the internal SNAP valves closed, the system pressure would rise above the threshold before the turbomolecular pump was able to be exposed to the chamber
- **Troubleshoot:** Collected data to define hysteresis to give the system time to evacuate the chamber low enough before opening the turbomolecular valve
- **Fixing the issue:** implemented the hysteresis and the controller could evacuate and vent our chamber safely, ensuring the turbomolecular pump is never exposed to pressure higher than allowed.

Final Testing & Resolutions

Figure 3A.

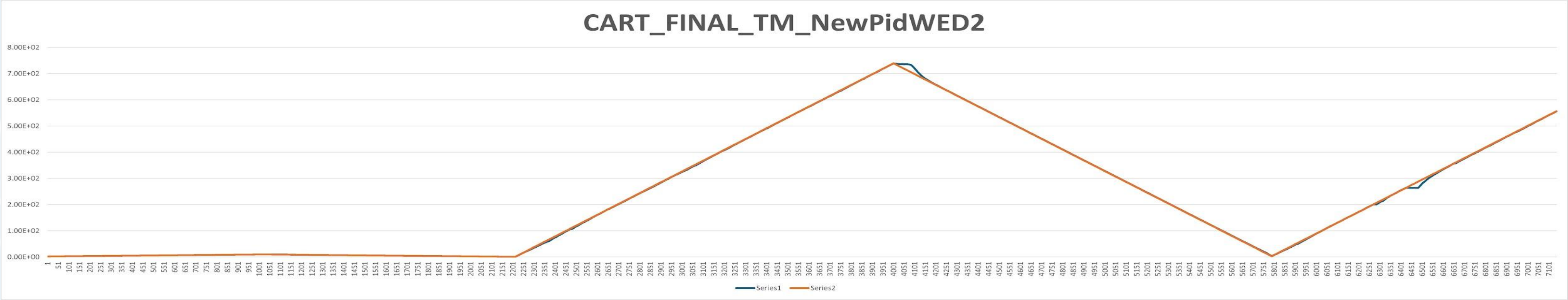


Figure 3B.

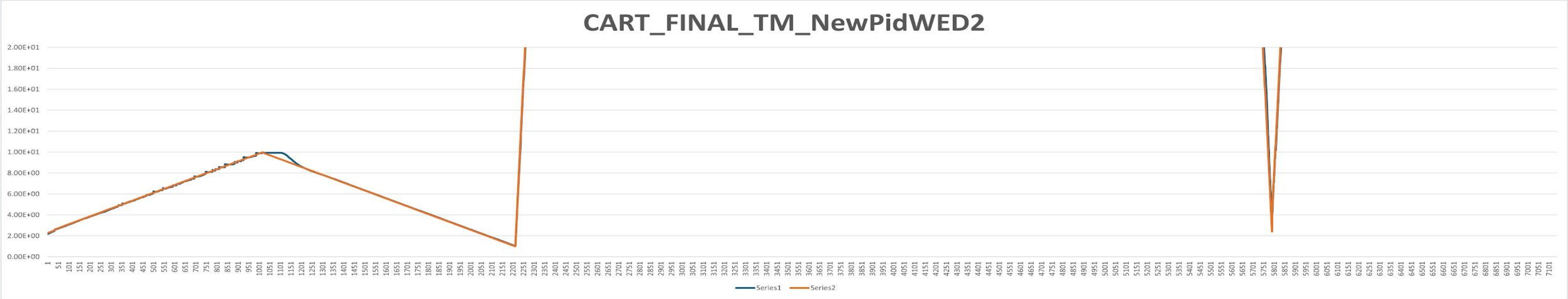
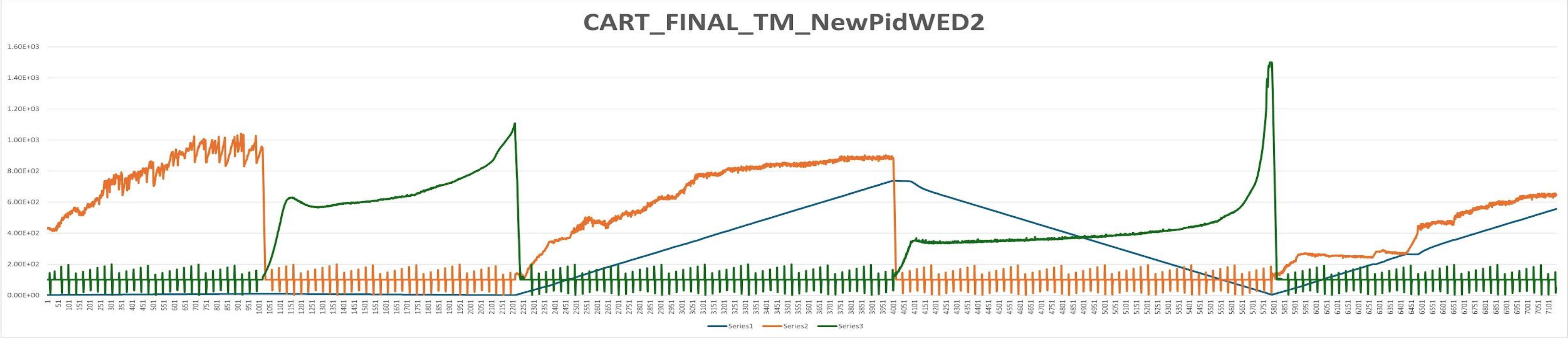


Figure 3C.



NOTE: The orange plot represents the control signal for the vent valve (pressure rise) while the green plot represents the control signal for the vacuum valve.

Final Tests to ensure smoothness of control during ramping

Resolutions:

- **More Motor Controls**
  - Filtering was utilized for this in order to average the numbers in order to achieve smoother profile when ramping up or down.
- **Preventive for Stepper Motor Indexing**
  - Controller periodically does a quick reset, allowing unusually long vacuum profiles

Results

A VACUUM SYSTEM TO MITIGATE REGOLITH INGESTION

By allowing for a controlled evacuation process that prevents the displacement of finer particles, this system addresses a critical need in lunar research. The successful testing ensures it meets the stringent requirements for lunar experimentation.

This approach not only facilitates current research endeavors but also paves the way for future studies aimed at understanding the behavior of regolith in a lunar environment, ultimately contributing to the broader goals of space exploration.

References

1. Go, GH., Lee, J., Chung, T. *et al.* Controlling soil disturbance of a lunar regolith simulant bed during depressurization in a vacuum chamber. *Sci Rep* 11, 1878 (2021). https://doi.org/10.1038/s41598-021-81317-1
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Thank You

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Questions ?