ENHANCING SPACE RESEARCH EFFICIENCY: VACUUM SYSTEM TO MITIGATE REGOLITH INGESTION

Tom Matthews, Tom Bassi, William Lewental, Vivianna Nguyen,
Tim Collins, and Evan Williams
The DigiVac Company

ABSTRACT

A vacuum system that can automatically execute a controlled evacuation of a chamber without disturbing the finer particles of the regolith is a necessity to perform experiments on simulated lunar regolith. Digivac developed such a system utilizing automated vacuum control technology and tested this system against parameters set by a lab that would be performing lunar experiments. Said system was also then condensed into a moveable, mobile cart to account for limited laboratory space.

INTRODUCTION

With the ever evolving space research and exploration industry, the tools that these labs and groups require should evolve with them. Especially as the research turns towards In-Situ Resource Utilization (ISRU) to expand upon lunar exploration. The problem that was presented was the lack of efficient and automatic systems that could execute a controlled evacuation that would minimize the movement of moon dust or fine particles.

Should regolith get ingested by a vacuum system, a pump's lifespan is shortened and experimental media is destroyed (ref. 1). Additionally, there was a preference for a neat, compact, and moveable system given limited lab space.

A vacuum system was thus developed that can gently evacuate and backfill vacuum vessels used for space testing. Upon pressing a button, the vacuum control system slowly evacuates a vessel, minimizing flow to avoid the movement of fine particles. Then, the controller automatically engages the high vacuum system to bring the chamber down to high vacuum. Thus, utilizing gentle evacuation based on Digivac's patented valve technology, the SNAP Vacuum Controller mitigates the movement of simulated moon dust, or fine particles, so that experimentation can be conducted more effectively. The system's integrated vacuum controller allows users to adjust the flow and setpoints to whatever fits their research requirements best.

In order to validate the system's efficacy, we had the system run through evacuation and purge cycles continuously. This was to simulate the parameters set by the client, which their lab would in turn use to simulate a lunar environment on which moon dust would be processed. The system was capable of maintaining a clean and controlled environment for lunar dust experiments, proven by the continuous cycling that the controller ran through. These cycles can run upwards of hundreds of hours giving users long stretches of time to complete experiments. Thus, this system gave scientists a simple yet effective tool to do the work they need to do.

SYMBOLS/NOMENCLATURE

Torr	Torr (measurement unit, i.e. a millimeter of Mercury)
ISRU	In-Situ Resource Utilization
SNAP	An automated vacuum controller platform developed by DigiVac
PID	Proportional, Integral, and Derivative; acronym for a closed loop feedback system

SYSTEM DEVELOPMENT

Configuration

The system (which can be seen illustrated by Figure 1) consisted of a SNAP Automated Vacuum Controller, turbomolecular pump, backing pump for the turbomolecular pump, a roughing pump, and the necessary fittings and ports - bundled into a neat and mobile cart with latch doors that can be wheeled around as necessary.

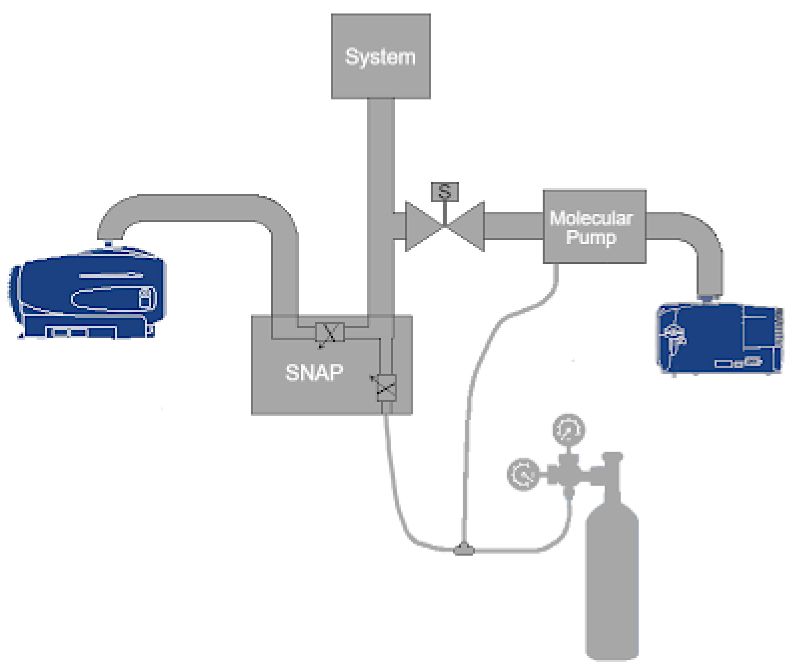


Figure 1. This is a graphic showing the configuration of the system we developed.

It was necessary for the system to prioritize achieving a low enough vacuum in order to collect materials for ISRU, but also to achieve high vacuum in as fast a time as possible, without disturbing regolith, in the most simple way possible. A 3.66 meter tall by 1.5 meter inner diameter chamber was used at the NASA Glenn Research Center to test soil mechanics, wherein the off-gassing at low pressure took about a full week to reach 10^{-5} Torr (ref. 2). NASA utilized a complex series of valves and pumps to achieve the end result. We were able to achieve a similar test system using simple push button controls, allowing scientists to focus on research and not on setting up vacuum systems.

Figure 2. - Photo of inside of the Cart, featuring rough/backing pumps and various hardware.

Development and Improvement of the SNAP

A crucial component of the system was the SNAP Vacuum Controller, a product DigiVac developed in order to automate the control of vacuum systems. The automated controller allowed for more precise control over the process, utilizing PID to refine the control. The SNAP controller can also utilize custom recipes, allowing operators to automate ramps and holds over hours that are so crucial for moon dust experimentation. A recipe can contain up to 24 steps, with the ability for gentle ramp rates that allow for the chamber to achieve high vacuum without disturbing the regolith.

Originally, the SNAP only had the ability to control one vacuum valve, which allowed a user to control the pressure from one pump. The system needed to slowly evacuate the chamber to about 500 mTorr, then open the valve up all the way to get the chamber down to 10^{-6} Torr. This type of system required a roughing pump as well as a turbomolecular pump. 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.

To pass from the rough pumping stage to the turbomolecular pumping stage, the internal SNAP valves have to close and an external valve opens. Through rigorous testing, Digivac found 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.

For the user interface, several updates were made to ensure a more streamlined control paradigm. When “Close” is pressed, all valves are closed. We 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. These features are all intended to give scientists easy to use tools to facilitate experimentation efficiency.

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.

TESTING AND TROUBLESHOOTING

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.

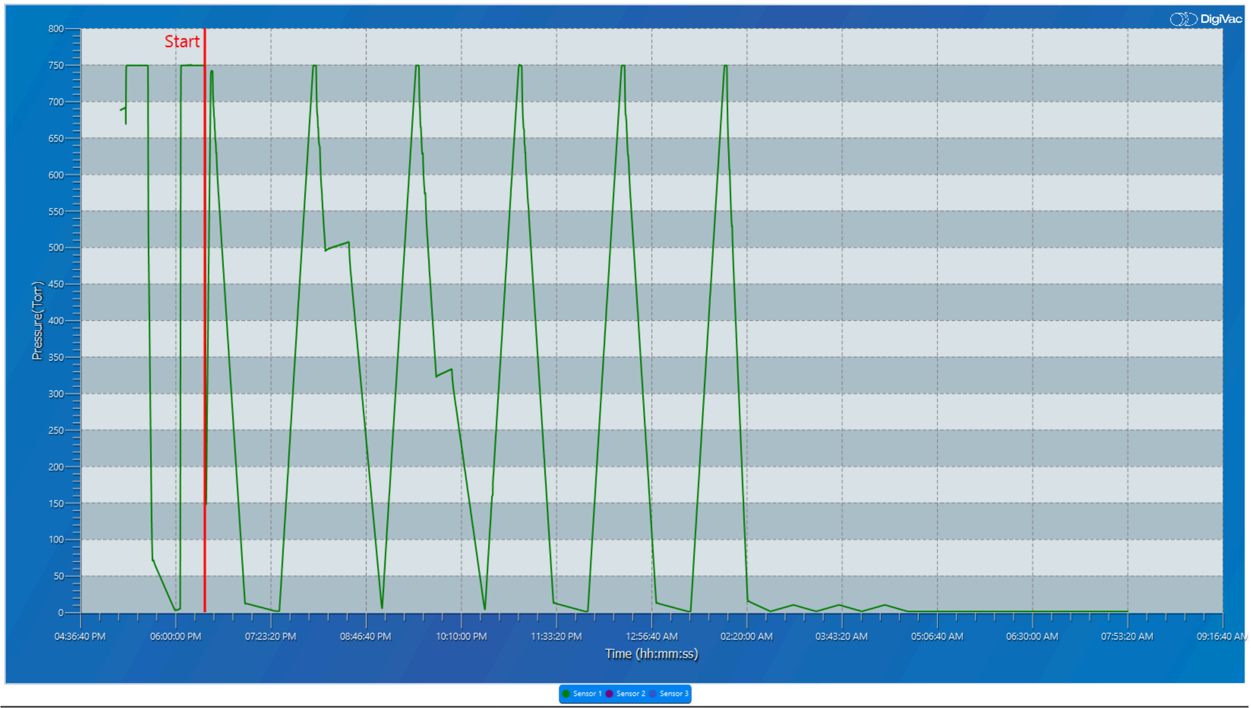


Figure 3A. - A run from 1 Torr to 10 Torr back to 1 Torr. Ramps successful using set recipes.

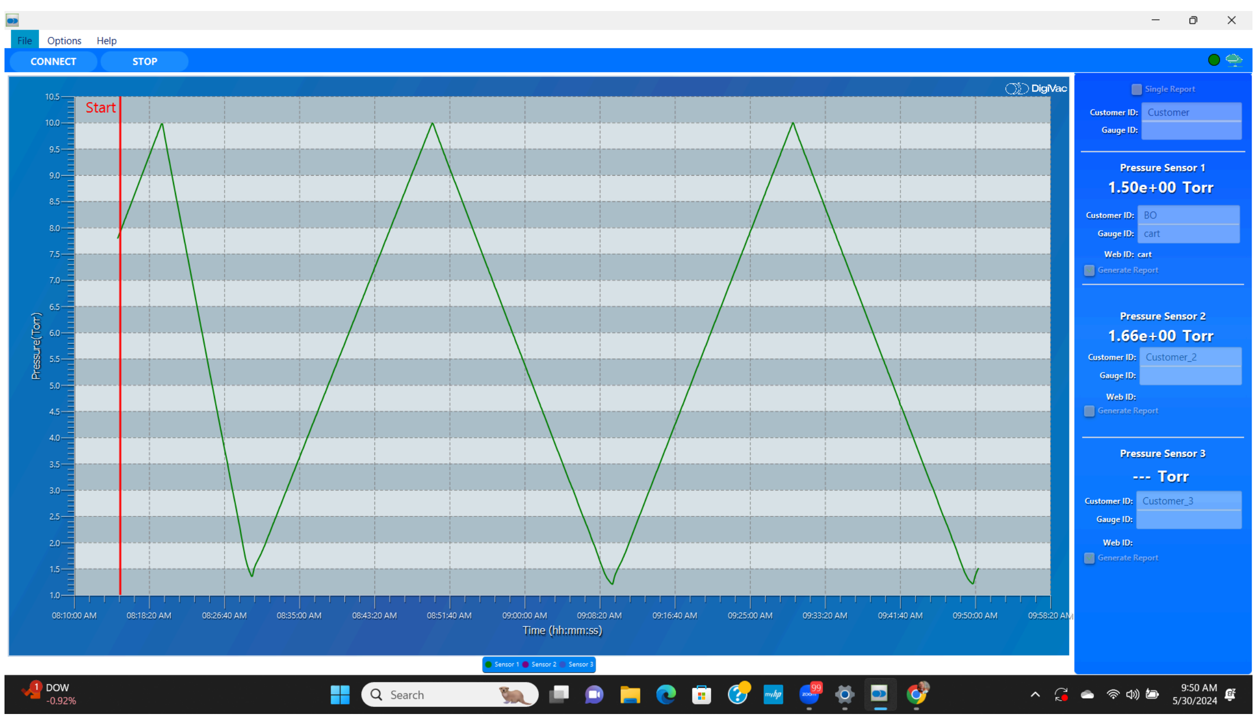


Figure 3B. - Exclusively testing 1-10-1 Torr ramps via set recipes. This graph displays the ramping during Recipe 7.

Displayed are graphs using the SNAP normally, without activating the external valve. The setpoints utilized in the recipes were running smoothly and there were no issues at first.

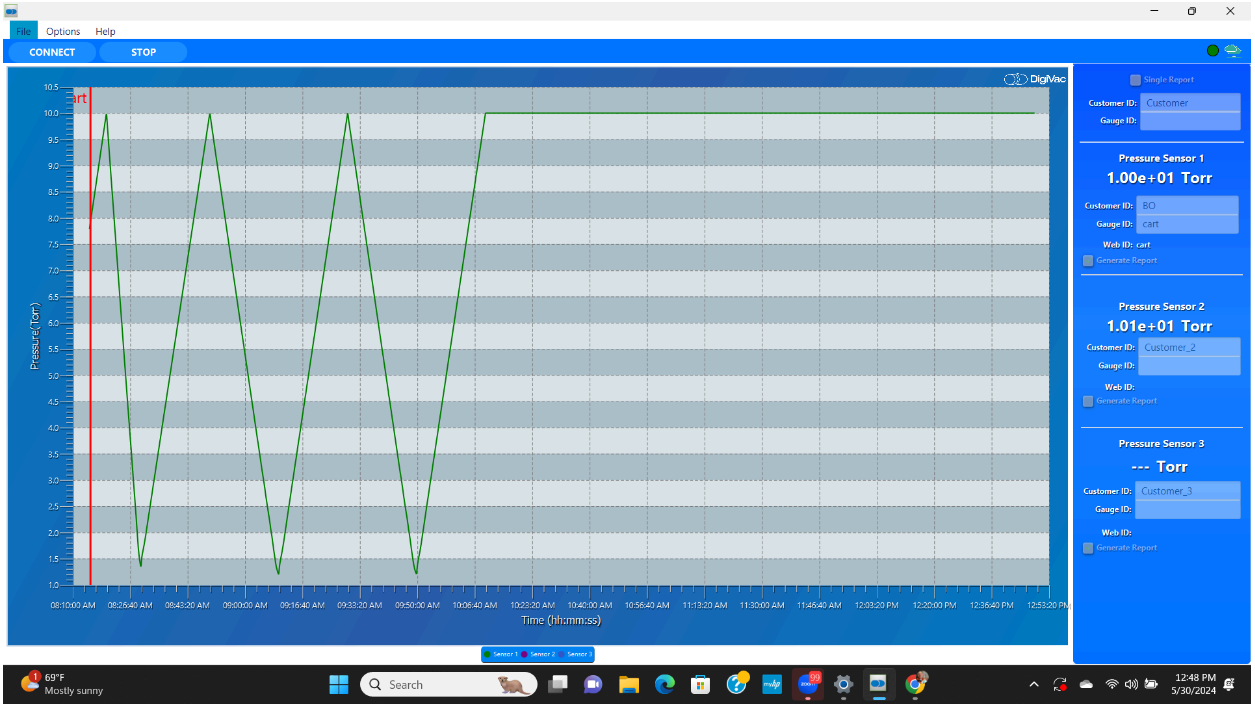


Figure 3C. - A bug was encountered upon activating the external valve.

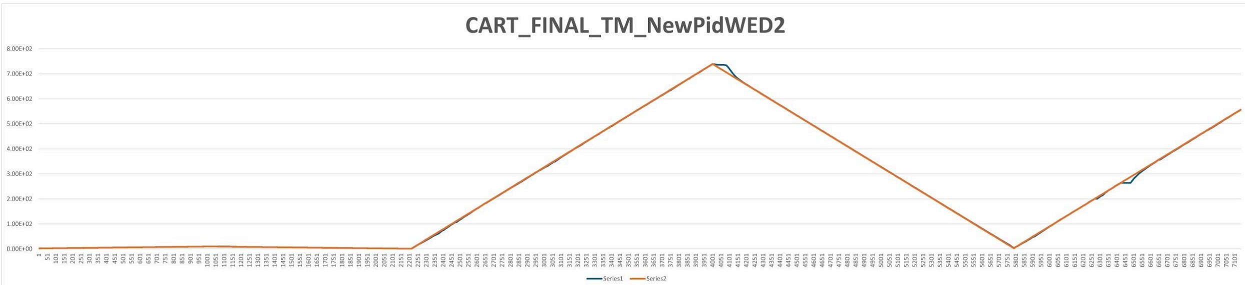
The SNAP, on a small vessel, was able to work for about 24 hours going in and out of all the modes with recipes, spanning about 20 hours. The same SNAP was then moved to the vacuum system cart where it exhibited interesting behavior.

Due to the larger vessel size of the final system (specified in the customer's parameters) - 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. Keep in mind it is harmful to the operation to expose turbomolecular pumps above certain pressures.

To troubleshoot the issue, we collected data to define a hysteresis we could add to give the system time to evacuate the chamber low enough before opening the turbomolecular valve. We also had to read the manufacturer's documentation for the given pump to ensure that the hysteresis did not load the pump beyond its recommended operation.

We 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.

Figure 3A.



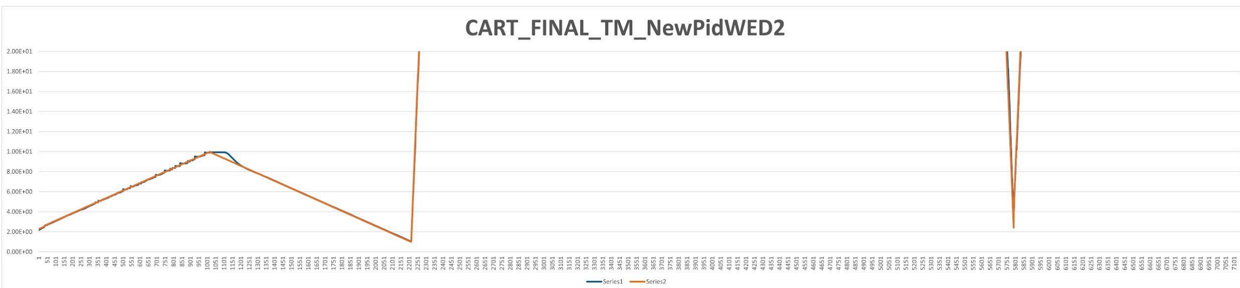


Figure 3B.

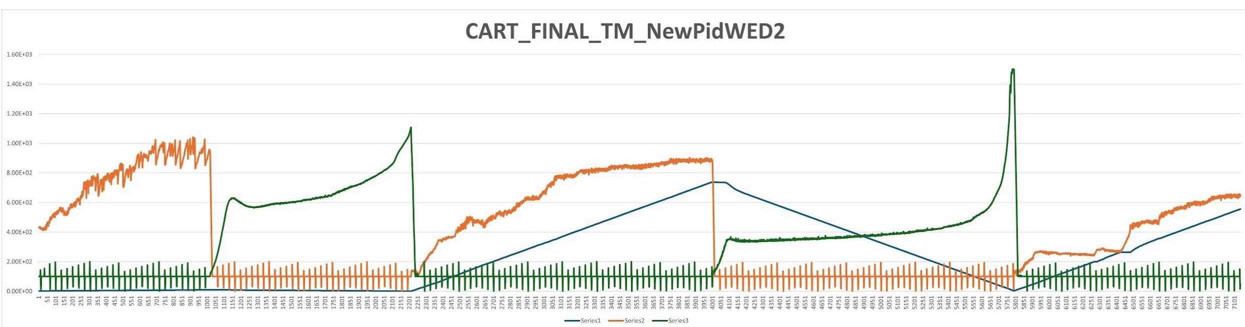


Figure 3C.

Figures 3A, 3B, and 3C represent some of the final tests to ensure smoothness of control during ramping. 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. More motor controls were implemented in order to achieve smoother profiles. Filtering was utilized for this in order to average the numbers so that a smoother up and down ramp could be achieved. This was after adjusting the PID values and software to achieve finer control than what had been needed of the SNAP controller and valve before.

Additional methods were implemented to prevent the controller from losing count of stepper motor indexing. The controller periodically does a quick reset, wherein it reverifies its home condition. This can be observed in Figure 3D, with the V shaped spikes being the control and the shorter spike is how the controller is figuring out where "home" is. This is what allows for unusually long vacuum profiles.

RESULTS

In summary, the development of an automated vacuum system by Digivac marks a significant advancement in experimental capabilities for simulated lunar regolith studies. 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 against established laboratory parameters demonstrates its efficacy and reliability, ensuring it meets the stringent requirements for lunar experimentation. Furthermore, the integration of this technology into a mobile cart design enhances its practicality, accommodating the constraints of limited laboratory floor space. This innovative 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
2. Kleinhenz, J. E. & Wilkinson, R. A. Development and testing of an ISRU soil mechanics vacuum test facility. In: *NASA Technical Report*, NASA/TM-2014–218389, 1–40 (2014).
3. O'Hanlon, J. F. *A User's Guide to Vacuum Technology*, Third.; Wiley-Interscience, 2003.