CHARACTERIZING THE PERFORMANCE OF THE WHEEL ELECTROSTATIC SPECTROMETER

Michael R. Johansen[1], P.J. Mackey[1], E. Holbert[1], J.S. Clements[2], and C.I. Calle[1]
[1] Electrostatics and Surface Physics Laboratory
NASA, Kennedy Space Center, FL 32899
[2]Department of Physics and Astronomy, Appalachian State University, Boone, NC 28608

***Abstract*— A Wheel Electrostatic Spectrometer has been developed as a surveying tool to be incorporated into a planetary rover design. Electrostatic sensors with various protruding cover insulators are embedded into a prototype rover wheel. When these insulators come into contact with a surface, a charge develops on the cover insulator through tribocharging. A charge spectrum is created by analyzing the accumulated charge on each of the dissimilar cover insulators. We eventually intend to prove charge spectra can be used to determine differences in planetary regolith properties. We tested the effects of residual surface charge on the cover insulators and discovered a need to discharge the sensor cover insulators after each revolution. We proved the repeatability of the measurements for this sensor package and found that the sensor repeatability lies within one standard deviation of the noise in the signal.**

I. INTRODUCTION

Current Martian surface exploration missions incorporate technologies to study the mineral make-up of the Martian regolith in search of volatiles, such as oxygen, that are of great importance for a manned mission to Mars. Volatiles can be extracted from the Martian regolith through In-Situ Resource Utilization (ISRU) processes and used to make drinking water for astronauts and fuel for the return trip to Earth [1]. Prior to a manned mission, it is important to determine location and concentrations of these volatiles and minerals. A surveying instrument is necessary to optimize the use of a Martian rover in search of these crucial elements.

We have developed the Wheel Electrostatic Spectrometer (WES) as a possible surveying tool to be incorporated into a Martian rover design. Electrostatic sensors with various cover insulators are embedded into a prototype wheel to analyze how these insulators charge against other materials. The sensor cover insulators – Teflon, Lucite, G10 and Lexan – were strategically chosen based on their respective locations in the triboelectric series [2]. Since each of the dissimilar cover insulators will charge differently, a charge spectrum is created when tribocharged against the same regolith simulant. In theory, Martian regolith types with different mineral compositions and volatile concentrations will charge the various cover insulators differently, thus allowing scientists to determine when the Martian rover is moving over a different type of regolith [3]. In addition, this instrument will enable studies of the Martian electrostatic environment, a subject not yet studied in detail on the Martian surface. It may even be possible to determine the type of regolith that the rover is traversing through a detailed spectral comparison [4]. Fig. 1 shows the Wheel Electrostatic Spectrometer.

Fig. 1. - WES prototype prepared to roll on Martian regolith simulant. The circular insulators are shown protruding from the surface of the wheel.

In this paper, we describe several tests to partially characterize the performance of the previously developed Wheel Electrostatic Spectrometer [2]. We examine the need to neutralize the surface charge after each wheel revolution. In addition, we assess the repeatability of the sensor responses.

II. ELECTRONICS

The electronics for the WES are based on the Mars Environmental Compatibility Assessment (MECA) project. This device was slated to fly on the 2001 Mars Surveyor Lander [5]. However, the lander portion of the mission was cancelled and the MECA electrometer was never flown.

The signal from each sensor head is sent to a one nF capacitor. The sensing head of the electrometer is made of a pad electrode with two concentric ring electrodes. The inner concentric ring serves as a guard while the outer ring acts as a ground. The voltage generated is amplified and sent to a routine for analysis. Fig. 2 demonstrates the tribocharging process while Fig. 3 displays the sensor head.

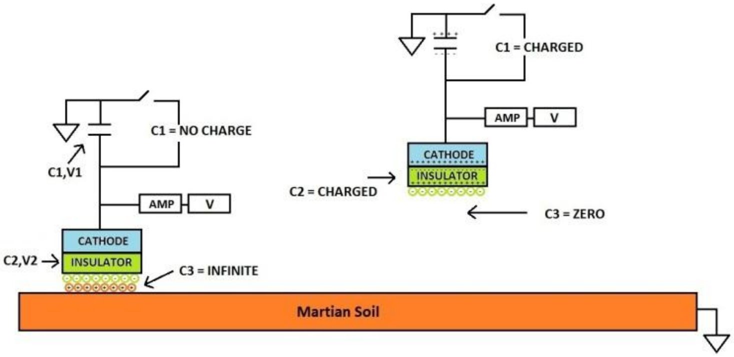

Fig. 2. - Simplified Electronics Diagram [5]. The sensor on the left shows the capacitor state when in contact with the regolith while the sensor diagram on the right displays the capacitor state after the insulator has been tribocharged**.**

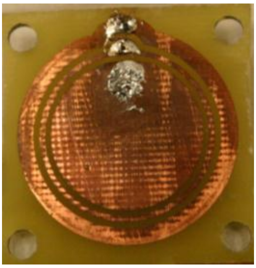

Fig. 3. - WES electronics sensor head. The sensor head is comprised of a large circular sensing pad and two concentric rings that act as a guard and a ground.

III. Experiments

The experiments presented in this section were conducted in a low humidity environment (< 4% RH). The data was taken from each sensor using a National Instruments 9201 Analog Input Module. A LabVIEW program was created to read signals from the analog input module and save the incoming data to a text file. The sampling frequency in each of the presented data sets is 100 Hz. The WES was rolled by hand in the discussed experiments.

A. Sensor Normalization

Sensor normalization was performed to ensure that all sensors had a similar response when exposed to the same electric field. To do this, a probe with rounded edges was placed 3 mm away from each sensor insulator and a Keithley 248 High Voltage Power Supply was used to supply 2 kV to the probe.

Fig. 4 displays the response from each sensor.

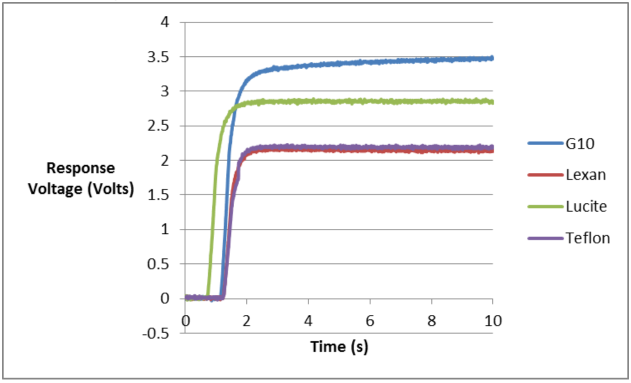

Fig. 4. - 2 kV applied to rounded probe with 3mm gap. Notice a drastic difference in the response voltage from the G10 sensor compared to the Teflon and Lexan sensors.

Fig. 4 demonstrates that a normalization factor was needed due to the variance in the amplification of each sensor. This variance is possibly the result of a loose resistor tolerance when the circuit was designed. A correction factor was applied to each sensor based on this data. The normalization factors for G10, Lexan, Lucite, and Teflon were found to be 1, 1.50, 1.21, and 1.61, respectively. These normalization factors were verified with an additional test that applied the normalization factors prior to saving the data. Fig. 5 displays the results from this experiment.

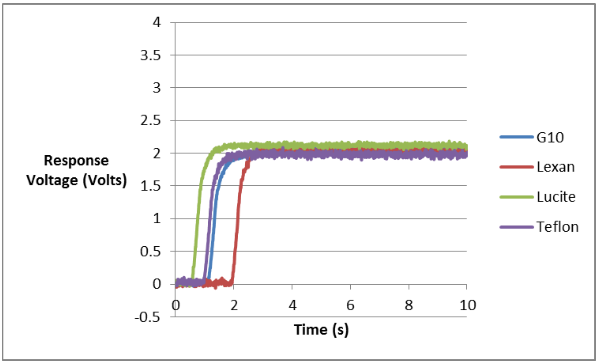

Fig. 5. - 2 kV applied to rounded probe with approximately 3 mm gap after normalization is applied. The sensors’ response voltages are nearly identical after the normalization is applied.

As shown in Fig. 5, the normalization factors greatly reduce the variance between the four sensors’ peak values. It should be noted that the gap distance is slightly greater than in the first experiment, as can be easily shown by the response voltage change in the G10 sensor. Minor gap changes cause great differences in the sensor response voltages.

B. Charge Neutralization

This experiment was designed to test the need to neutralize the surface charge on the insulators after each wheel revolution. JSC1A lunar simulant was used in each test [7]. It should be noted that post processing was completed on each of the data sets displayed. A 6-point moving average was used to improve the signal-to-noise ratio and the normalization factors described in *Sensor Normalization* were applied.

In the first experiment, the wheel was rolled over the simulant to allow each insulator to be tribocharged. After the 10-second data acquisition period was complete, the capacitor was discharged. While discharging, a 3M Benchtop Air Ionizer was used to neutralize the surface charge on each of the tribocharged insulators. This process was repeated several times. Fig. 6 shows the Lucite sensor response from the previously described experiment.

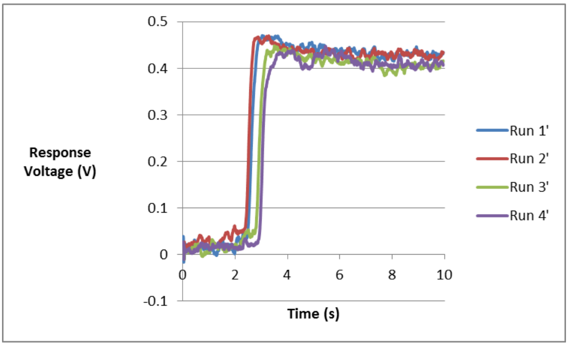

Fig. 6. - Lucite rolled on JSC1A lunar simulant. The surface charge was neutralized after each run. Lucite separates from the regolith simulant at approximately 3 seconds. The shape and the magnitude of the sensor response voltage is approximately the same in each trial.

This experiment was repeated without the use of the air ionizer so that the surface charge remained on the insulators after each trial. The capacitor was discharged after each trial. In the first run, the insulator has no surface charge. In all subsequent trials, the residual surface charge remains on the insulator from the previous run. Fig. 7 displays the data from the Lucite sensor from this experiment.

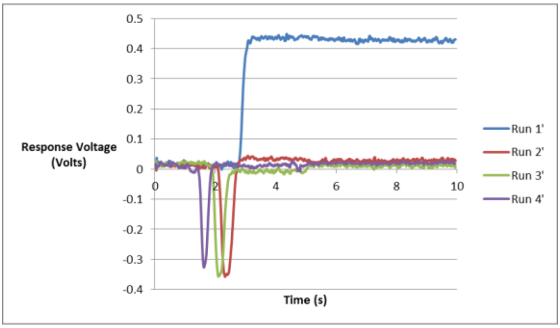

Fig. 7. - Lucite rolled on JSC1A simulant. The surface charge was not neutralized after each run. Lucite separates from the regolith simulant at approximately 2.5 seconds.

Fig. 6 and Fig. 7 illustrate the need for the sensors to be discharged after each revolution. When the surface charges are neutralized, a clear and stable response is observed. When the surface charges are not neutralized, the sensor response peaks with an opposite sign as what should be expected and rapidly returns to a near 0 volt response.

This data also demonstrates it may not be necessary to clean the insulators after each revolution. The peak response voltage of Lucite returns to approximately the same value without any cleaning.

C. Sensor Response Repeatability

Another task to characterize the performance of the WES was to investigate the repeatability of the sensor responses during electrostatic testing. To analyze the electrostatic response repeatability, due care was taken to ensure identical test conditions. The relative humidity was monitored to ensure the level did not exceed 4% during testing. The regolith was mixed after each trial to limit the effects from variation in surface compactness. The insulators' surface charges were neutralized prior to each test. Fig. 8 displays a sample of the data from the trials.

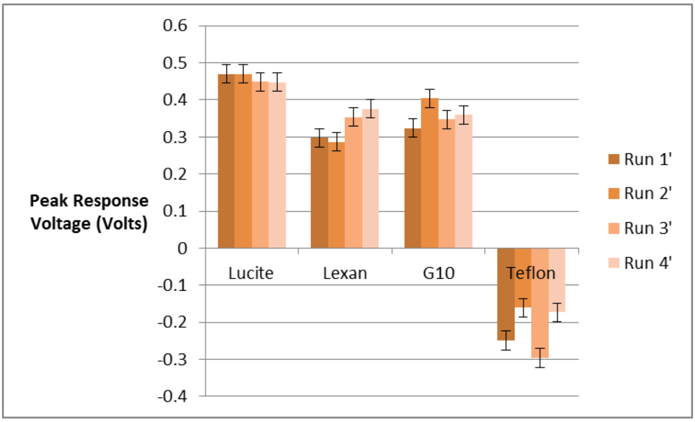

Fig. 8. - Comparison of 4 trials. WES was rolled on JSC1A lunar simulant. The data demonstrates when these materials are tribocharged against lunar regolith, a level of repeatability can be expected.

The error bars in Fig. 8 represent plus or minus one standard deviation of the noise in the first 130 data points, approximately .025 volts for these experiments. Based on the data presented, with the exception of the Teflon sensor, the sensor responses appear to be repeatable within one standard deviation of the noise. Peak voltages lying outside of their respective sensors error bars are likely associated with a non-automated rolling system, allowing for variation in speed of contact, duration of contact, and pressure of contact.

IV. CONCLUSIONS AND FUTURE WORK

We have shown the sensor responses to be repeatable to within one standard deviation of the noise. We demonstrated the need to neutralize the surface charge on the cover insulators. These experiments also demonstrated that the insulators may not need to be cleaned after each wheel revolution. The electrostatic sensors used in the tests reported here have now been redesigned to increase the signal-to-noise ratio, to make each sensor independent, and to reduce the variance between each sensor. Testing with these new electrostatic sensors is currently underway. Future testing will include rolling WES on a variety of lunar and Martian regolith types to compare the spectral response between simulants. An automated WES rolling system is being developed to increase the repeatability between trials. Based on the data presented in *Charge Neutralization*, there will be a need for a Martian atmospheric static elimination tool. This tool is currently in the planning stages.

REFERENCES

[1] G.B. Sanders, M.A. Interbartolo, W.E. Larson, R.P. Mueller, A.C. Muscatello, "Early In-Situ Resource Utilization (ISRU) Leading to Robust Sample Return and Human Exploration Missions", presented at Concepts and Approaches for Mars Exploration, Houston, TX, June 12-14, 2012, Presentation #4208.

[2] C.I. Calle, J.G. Mantovani, C.R. Buhler, E.E. Groop, M.G. Buehler, and A.W. Nowicki, "Embedded Electrostatic Sensors for Mars Exploration Missions," *Journal of Electrostatics*, vol. 61, pp. 245-257, July 2004.

[3] M.G. Buehler, R.C. Anderson, S. Seshadri, M.G. Schaap, "Prospecting for In Situ Resources on the Moon and Mars Using Wheel-Based Sensors," *Aerospace Conference, 2005 IEEE*, pp. 607-616, March 2005.

[4] C.I. Calle, "Sensors to Characterize the Properties of Martian Regolith," presented at Concepts and Approaches for Mars Exploration, Houston, TX, June 12-14, 2012, Presentation #4206.

[5] M.G. Buehler, L. J. Cheng, O. Orient, D.P. Martin, R.H. Gompf, C.I. Calle, J.A. Bayliss, and J.L. Rauwerdink, "From Order to Flight in Eighteen Months: The MECA/Electrometer Case Study," presented at The 2000 IEEE Aerospace Conference, Big Sky, Montana, Mar. 2000.

[6] M. Buehler, L. Cheng, O. Orient, M. Thelen, R. Gompf, J. Bayliss, J. Rauwerdink, "MECA Electrometer: Initial Calibration Experiments," *Electrostatics 1999: Proceedings of the 10th International Conference*, vol. 10, Cambridge, pp. 189-196, 1999.

[7] D.S. McKay, J.L. Carter, W.W. Boles, C.C.Allen, and J.H. Alton, "JSC1: A New Lunar Soil Simulant," presented at American Society of Civil Engineers - Engineering, Construction, and Operations in Space IV, Albuquerque, NM, Feb. 26 – Mar. 3, 1994.