A Feasibility Study Of The Wheel Electrostatic Spectrometer

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Abstract— Mars rover missions rely on time-consuming, power-exhausting processes to analyze the Martian regolith. A low power electrostatic sensor in the wheels of a future Mars rover could be used to quickly determine when the rover is driving over a different type of regolith. The Electrostatics and Surface Physics Laboratory at NASA's Kennedy Space Center developed the Wheel Electrostatic Spectrometer as a feasibility study to investigate this option. In this paper, we discuss recent advances in this technology to increase the repeatability of the tribocharging experiments, along with supporting data. In addition, we discuss the development of a static elimination tool optimized for Martian conditions.

I. INTRODUCTION

In order to substantially reduce the launch mass of future exploration missions, NASA is developing technologies to transform resources found on planetary bodies into consumables needed for human exploration. NASA is currently conducting research on methods to convert carbon dioxide found in the Martian atmosphere into products that future astronauts will need, such as oxygen and water [1]. In addition, researchers are developing additive manufacturing techniques with planetary regolith to build structures for human inhabitants and support equipment [2]. These processes are part of a larger overarching ideology known as In-Situ Resource Utilization (ISRU), or "living off of the land."

NASA must first characterize the Martian regolith in order to understand what ISRU processes are necessary for future human exploration of the Red Planet. Current Martian exploration missions require the use of time-consuming processes to identify the composition of the regolith. Wheel-based sensors could be used to determine when the rover is driving over a different material, allowing decision making algorithms to determine if the prospecting rover should stop to perform a thorough, time-consuming analysis of the regolith. With this type of operational structure, the mission could see a great increase in the operational efficiency of the rover in search of elements of interest [3].

The Wheel Electrostatic Spectrometer (WES) was developed to investigate the use of electrostatic wheel-based sensors in a Martian rover. WES was derived from the Mars Environmental Compatibility Assessment (MECA) Electrometer, an electrostatic analysis instrument designed to fly on the cancelled 2001 Mars Odyssey mission [4]. Electrostatic sensors in the wheels of a Mars rover could be used as a prospecting aid by analyzing the electrostatic response with every wheel revolution [5]. In addition, this data can be used to study how materials electrostatically respond when tribocharged against Martian regolith, a subject of great importance but not yet studied on the Martian surface.

II. PLANETARY REGOLITH AND REGOLITH SIMULANTS

The Spirit, Opportunity, and Curiosity rovers were outfitted with Alpha Particle X-ray Spectrometers (APXS) to analyze the chemical composition of the Martian regolith. Fig. 1 displays the results from these analyses [6]. The results of these tests indicate that the top layer of the Martian regolith is relatively uniform. Similar results were found during the Viking 1, Viking 2, and Pathfinder missions [7]. This global uniformity of the top layer of dust is thought to be caused by the frequent global dust storms experienced on Mars [8].

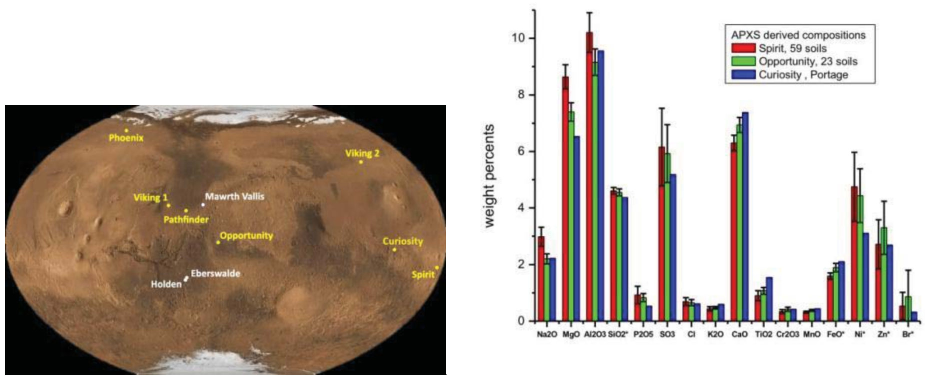

Fig. 1. Chemical composition of Martian regolith from recent Martian sites

Although Mars' top layer of regolith has been found to be mostly uniform, the subsurface regolith may hold pockets of materials that are not dispersed evenly throughout the planet. The Mars Exploration Rover Opportunity, through an operation known as trenching, discovered dissimilarity in hematitic deposits on the surface when compared to similar samples taken from the subsurface [9]. Also, the Thermal Emission Spectrometer on board the Mars Global Surveyor found a significant variation in volcanic material in the darker colored regolith on the Red Planet [10].

NASA's Johnson Space Center has developed a Martian simulant regolith in support of research and engineering studies, known as JSC Mars-1. While not identical, this simulant roughly estimates the chemical composition of true Martian regolith. JSC Mars-1 simulant was used as one of the tested regolith simulants in this feasibility study. Fig. 2 compares the chemical composition of JSC Mars-1 simulant to results from the regolith analysis on the pathfinder mission. JSC-1A lunar regolith simulant was also used in this study. A comparison with the JSC Mars-1 simulant is also shown in Fig. 2.

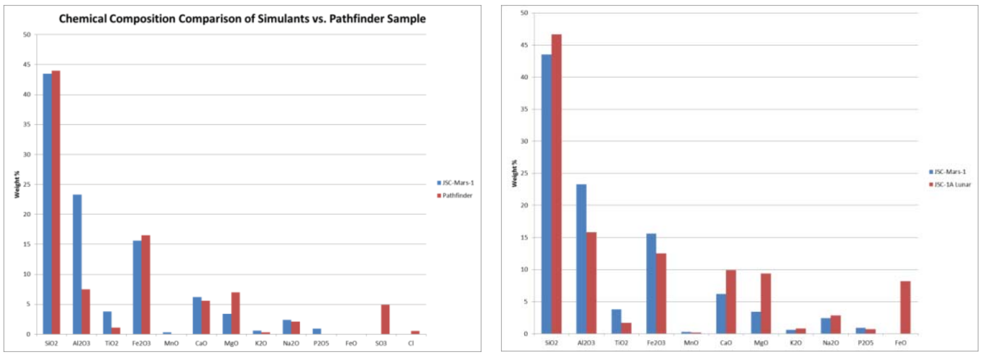

Fig. 2. Comparison of regolith simulants [11]

III. WES DESIGN AND TEST CONFIGURATION

Early WES prototypes suffered from severe slipping in regolith simulants. In order to minimize slipping, WES was outfitted with treads and weighted with two aluminum disks on the interior of the wheel. WES fully assembled weighs approximately 2.25 kg and is roughly 13 cm in diameter. The treads protrude roughly 3 mm from the surface of the wheel. The current WES prototype analyzes electrostatic charge on Lucite, Teflon, G10, and Lexan. The second generation WES prototype is shown in Fig. 3.

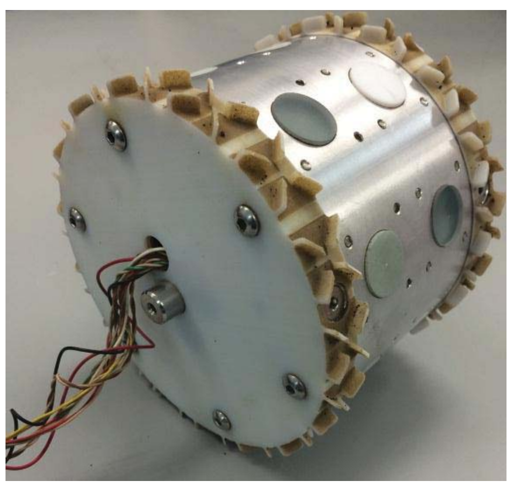

Fig. 3. Wheel Electrostatic Spectrometer Second Generation Prototype

A precision rolling mechanism was created to roll WES repeatedly over granular materials. An acrylic tray was fabricated to house the regolith simulants to be tested and placed inside of an 80/20® extruded aluminum frame. A rolling trolley controlled by a DC motor was attached to WES. Fig. 4 displays the WES rolling mechanism.

Fig. 4. WES Rolling Mechanism

WES uses an amplification circuit with sensing, guard, and ground electrodes. The sensing head and amplification circuit are assembled on a two-layer printed circuit board, to minimize the distance the unamplified signal travels. The protruding materials are approximately 2 cm in diameter. Fig. 5 displays the electrostatic sensor and a representation of its configuration in WES.

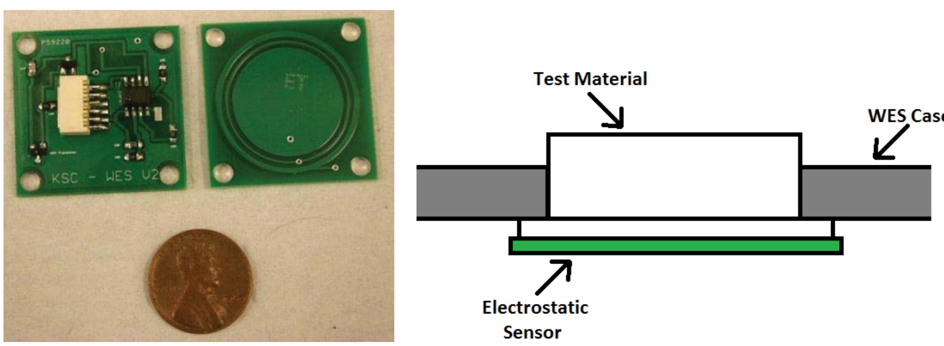

Fig. 5. Electrostatic Sensor Second Generation Prototype

IV. WES TESTING

Care was taken to ensure that the WES test conditions were nearly identical for all trials. One of the main concerns for this testing was the Relative Humidity (RH) prior to and during testing. The WES test apparatus was placed inside a humidity controlled chamber, set to 0% RH. The regolith and test apparatus were left to acclimate to this 0% RH environment for 12 hours. In addition, WES was rolled back and forth over the simulated Martian regolith numerous times prior to testing to ensure nearly identical simulant compactness over the many trials.

WES was rolled over each of the tested regolith simulants 25 times. At the end of each trial, the surface charge on each of the test insulators was neutralized with an air ionizing fan. After the surface charge was neutralized, each electrostatic sensor was zeroed. This process was adopted based on information gained from previous testing [5]. The wheel was rolled at approximately .3 cm/s to roughly match the average angular velocity of the current Mars Science Laboratory wheels. Fig. 6 displays the data from a typical trial.

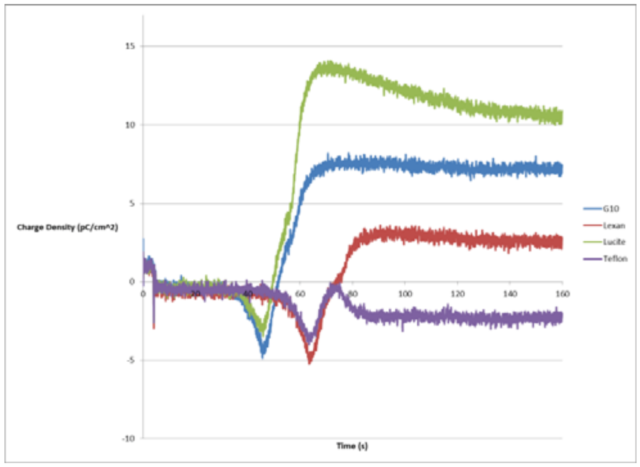

Fig. 6. WES rolled against JSC Mars-1 simulated Martian regolith

Three regolith simulants were used to analyze the electrostatic response of the test materials - Bulk Mars -1, JSC-1A >10µm, and JSC-1A >200µm. The data shown in Fig. 7 displays an average of the peak charge density of 25 trials for each regolith type, with error bars representing the standard deviation of the peak charge for each sensor. It is apparent that the electrostatic response is different for each of the tested regolith simulants. This data indicates that a difference in grain size could be determined, in part, by the electrostatic response of materials outfitted in the wheels of a future Mars rover. This experiment supports the claim that a difference in chemical composition in Martian regolith could be sensed with wheel-based electrostatic sensors.

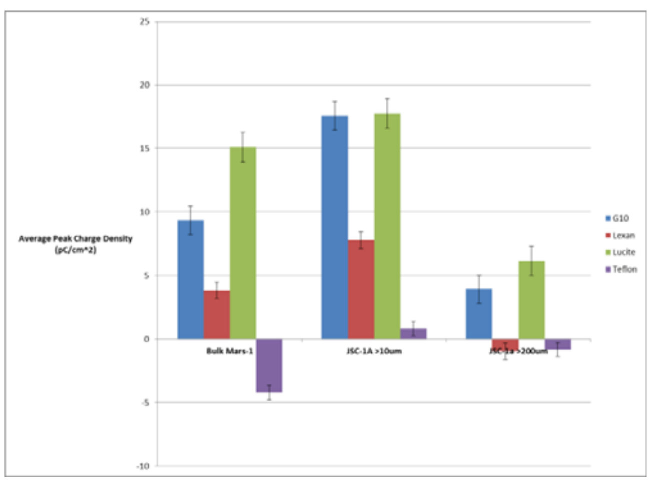

Fig. 7. WES Test Results

At first glance it appears that Teflon charges very little against the regolith simulants. However, contact and separation must occur for the electrostatic sensor to indicate a charge on the tested material. A significant amount of dust adhesion on Teflon was noted during a majority of the trials, explaining Teflon's masked actual surface charge. It is hypothesized that strong electrostatic forces prevented the regolith simulant from separating from the Teflon test material due to Teflon's charge affinity. Fig. 8 displays the electrostatic dust clinging of JSC Mars-1 simulant on Teflon, while simultaneously demonstrating the absence of this effect in G10. This suggests that future Mars missions should minimize the use of Teflon in favor of other materials that may have similar properties without the unwanted electrostatic dust clinging tendency.

Fig. 8. Electrostatic dust clinging of Teflon (Top Center) and G10 (Bottom Center)

V. MARTIAN PRESSURE STATIC ELIMINATION TOOL

As determined in previous research, the surface charge of each of the test insulators must be neutralized in order to obtain repeatable results [5]. Another portion of this feasibility study provided a proof-of-concept demonstration that a static charge eliminator could be developed for Martian atmospheric conditions. The Martian atmosphere is comprised of mostly carbon dioxide at 7 torr, making it inherently difficult to reach the voltages used in terrestrial high voltage static eliminators.

The Electrostatics and Surface Physics Laboratory at NASA's Kennedy Space Center relied on its expertise in using high voltage equipment in Martian atmospheric conditions to develop the Martian Pressure Static Elimination Tool. The static eliminator electrode geometry consisted of a central high voltage needle point encircled by a grounded electrode roughly 2.5 cm in diameter, as shown in Fig. 9.

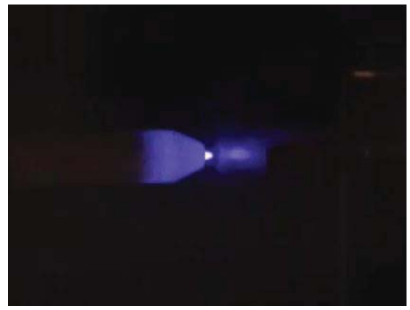

Fig. 9. Martian pressure static elimination tool geometry (left), Static eliminator corona (right)

High voltage positive and negative DC pulses were used as the static elimination control signal. A duty cycle of 10%, amplitude of ±1.2 kV, and frequency of 10-100 Hz were used for all testing. A parallel plate capacitor was fabricated using two large brass sheets, with a measured capacitance of 180 pF. The static elimination tool was placed in a vacuum chamber on a translating mechanism to vary the distance between the charged plate and the static eliminator. A brass sphere was connected to one of the plates of the capacitor, while the other plate was connected to ground. A translating high voltage contact was used to charge the capacitor while under Martian atmospheric conditions. To charge the capacitor, the high voltage contact was moved to make contact with the sphere. The HV contact was retracted from the sphere once the capacitor was charged. A non-contact voltmeter was used to read the voltage on the sphere during testing. The voltage on the capacitor was monitored prior to testing to ensure that the observed voltage reduction was a result of the static elimination tool and not leakage current. Fig. 10 displays the test configuration previously described.

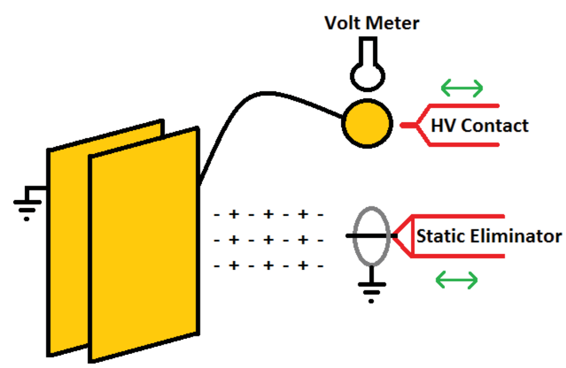

Fig. 10. Static eliminator test configuration

To test the effectiveness of the Martian Pressure Static Elimination Tool, the frequency was varied between 10 and 100 Hz and the distance between the static eliminator and the target capacitor was varied between 5 and 25 cm under Martian atmospheric conditions. It was discovered that increasing the frequency and decreasing the distance decreased the time needed for static elimination. However, even at a distance of 25 cm this tool was able to reduce the capacitor voltage to less than 20% of the initial charge within a fraction of a second. Fig. 11 displays a sample of the results from these tests.

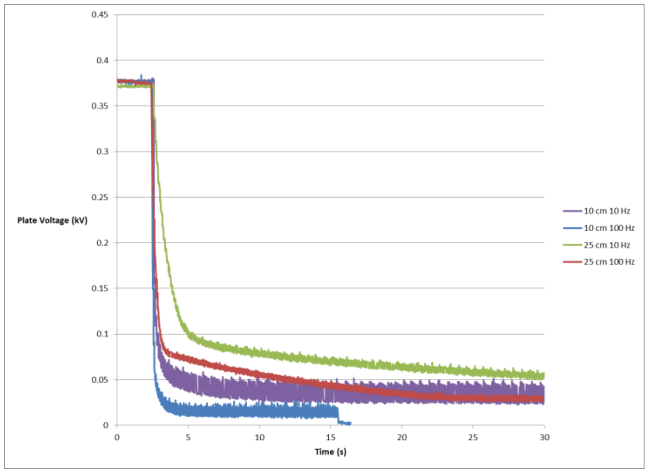

Fig. 11. Discharging a 180 pF capacitor in a simulated Martian atmosphere

A similar test to the previously described test was done with the WES geometry. To create a parallel plate capacitor that would match the capacitance of the WES geometry, copper tape was placed on the top of the Teflon insulator and on the back of the electrostatic sensor. The same method for charging the capacitor in the previous experiment was also used for this experiment. The static eliminator was placed approximately 10 cm from the target. Fig. 12 shows the test configuration for this experiment.

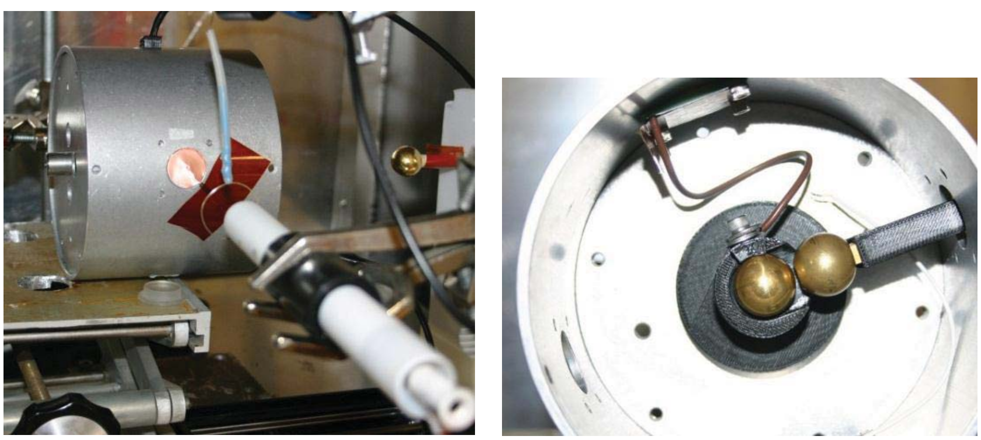

Fig. 12. Experimental setup for testing with WES geometry

The WES based capacitor was charged to approximately 360 Volts and monitored for several minutes to ensure minimal leakage current. Fig. 13 displays the data from this testing. In one trial, the capacitor was charged with a positive voltage. In a second trial, the capacitor was charged with a negative voltage. The positively charged capacitor's voltage decreased to less than 10% of the original voltage within .04 seconds. For the negative voltage trial, the capacitor voltage dropped below 10% within .3

seconds. The results indicate that in this geometry, a high voltage ion generation static eliminator can be used to rapidly and substantially remove static charge built up on a surface in a Martian atmosphere.

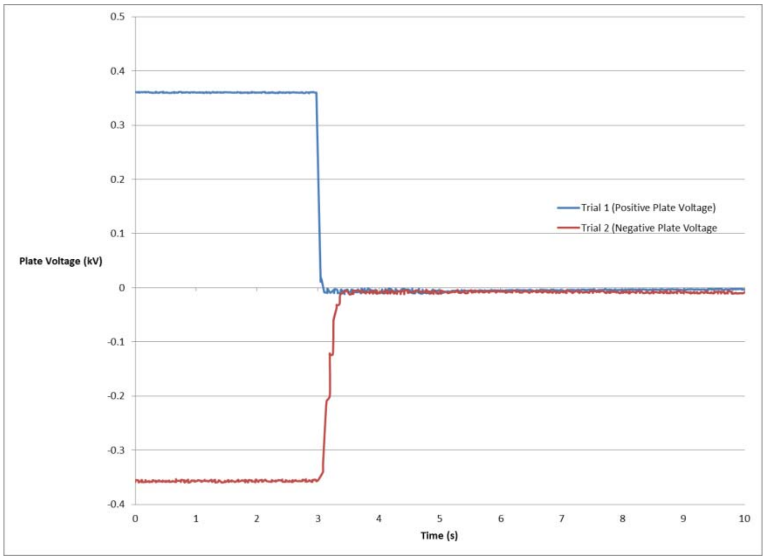

Fig. 13. Static Elimination Testing on WES in a simulated Martian atmosphere

VI. CONCLUSIONS

The tests discussed in this paper demonstrate the feasibility of wheel based electrostatic sensors to act as a prospecting aid on the Martian surface. A difference in electrostatic response was demonstrated when rolling against different regolith simulants and grain sizes in a well-controlled environment, indicating that WES has potential to drastically increase the efficiency in searching for materials with certain properties. While this instrument is not designed to replace any existing equipment, as the information retrieved from current analysis tools is far superior to that of the developed electrostatic sensor array, it may alert mission scientists when the rover is driving on a different type of material. In addition, a proof of concept Martian pressure static eliminator was developed, which is an enabling technology for wheel based electrostatic sensors.

Future work will focus on testing with regolith simulants that have been doped with materials of interest for ISRU processes. To further test the feasibility of WES, this instrument should be incorporated into an existing field demonstration rover to better understand how the electrostatic responses of the test materials change in an operational environment, where key variables will be less controllable.

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