DUST WIPER MECHANISM FOR OPERATION IN MARS

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ABSTRACT

REMS UV sensor on Mars Science Laboratory rover shall be pointing to the Martian sky to take measurements of the UV flux received by the surface. From the beginning, deposition of dust particles on the sensor head was considered by the scientific team a major concern. Such unpredictable phenomena may attenuate the signal received by the optical sensor, and must be considered by far the largest source of error in the sensor.

Several dust mitigation strategies such as the use of magnets to slow down the dust deposition where evaluated. Finally, a robotic dust wiper was selected as error mitigation system. A UV sensor model with a dust wiper was designed, constructed and pre-qualified for MSL mission.

Several brushes where fabricated and tested as to maximize its efficiency with submicron particles dust.

Technology performance and qualification results are presented in this paper. The proposed Dust Wiper technology proves to be a simple, yet effective solution to mitigate the error caused by dust on optical sensors or solar panels operating on dirty atmospheres such as that of Mars. Using a novel actuator technology based on SMA, the solution represents a very small increase in Mass and a major improvement in Instrument performance.

The developed actuator proved to be a non precise, yet very light rotary actuation technology. For this reason, this novel actuator is now being considered for other space applications where movement accuracy is not demanding but mass budget for the mechanism is very low.

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1. INTRODUCTION

A robotic dust wiper technology based on a novel actuator is presented herein. The technology has been developed to clean surfaces from deposited micron-sized dust particles (aerosols). In particular, it has been designed and tested to clean the surface of optical sensors operating on the surface of Mars. It may have further cleaning applications (solar panels, sensors, cameras, windshields etc), and in particular it may be useful whenever a robust and light cleaning mechanism is required to be operated remotely (such as for space missions, or autonomous monitoring stations) or in human hostile conditions.
The actuator technology, specifically developed for integration in the dust wiper system, is extremely light and robust. It may also be of interest for future Mars operated mechanisms such us valves, openings, or struts demanding minimum mass and greatest robustness.

1.1. MARTIAN DUST

The Martian atmosphere contains a significant load of suspended dust. Dust settles out of the atmosphere onto exposed surfaces; the effect of the dust coverage can be directly seen in the output of the rovers solar arrays [1-3].

It was found that Martian dust settling on MER rovers solar array has different properties from that of atmospheric dust measured from solar scattering properties. Evidence for a three-component particle distribution was observed [4]:

- *Airbone dust:* Primarily particles of ~1-2 µm radius, which stay suspended in the atmosphere for long periods. Airborne dust has magnetic properties, since it is primarily composed by composite silicate particles containing as a minor constituent the mineral magnetite [6].
- *Settled dust:* Particles > 10 µm radius, which are raised into the atmosphere by wind or dust-devil events, but settle out of atmosphere. Deposits on the surface are significantly larger than the particles measured in the atmosphere. This could be either distinct larger particles, or conglomerate particles formed by agglomeration of micron-scale particles.
- *Saltating particles:* Particles > 80 µm, which move primarily by saltation. Note saltating particles are

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seen to reach MER rovers deck, a meter above the surface.

Pathfinder rover included the Mars Adhesion Experiment to quantify the deposition of dust on the rover solar panels [1-3]. Rate of dust deposition was measured to be 0,18% per sol (where complete coverage would be 100%). Note the dust deposition rate depends on the airbone dust opacity (which at the time was 50%), and the inclination of the surface (which at the time was horizontal). The angle of the sun does not appear to modify the dust adhesion patterns on vertical surfaces [5].

Dust magnetic properties are currently being studied by MER rovers. Different magnets where exposed to airbone dust. It was found that airbone dust particles contain a ferrimagnetic mineral, the amount of which varies somewhat from particle to particle [6]. Settled dust and saltating particles are not being characterized by the experiment and therefore their magnetic nature is still unknown.
Several technologies are currently being studied to overcome the problem of dust deposition on solar panel or optical instruments operating on Mars surface. These technologies can be classified in:

Passive technologies, aiming at reducing the rate of deposition of dust on a certain surface. The use of permanent magnets [7], or the use of a cover that is opened only when needed [1-3] are examples of passive technologies.

For long operated systems, or instruments where a maximum quantity of dust is permitted, passive techniques are not recommended.

Active technologies are those aiming at cleaning a surface covered by dust. Dust wiping can be accomplished by a brush, or by electrodynamics fields [8-9]. The first technique is limited by the resolution of the brush, while the latter is based on the assumption that the mass to magnetic charge ratio of the dust is low enough to be repelled by the electromagnetic field. The use of electrodynamics fields requires high voltage generation and distribution across the surface, which increases the complexity of the electronics and of the harness. This implies a large impact on mass due the use of this technology. Dust wiping using a brush will be described further in this document. It will be shown that Dust wiping using a brush is an effective, yet light and simple method of dust removal.

During the early stages of this study, a passive approach based on magnets was analyzed by testing two type of dust particles deposited on top of a magnet. A highly magnetized dust, and an unmagnetized dust were tested. In both cases the dust was electrically charged, simulating Martian airbone dust conditions. Fig. 1 shows the result of this preliminary test that was conducted on the Martian Dust Simulation Chamber (the chamber is described further in this document).

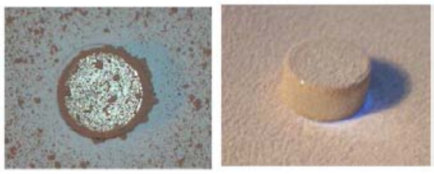

Fig 1. Test of magnets as dust repellent: Magnetized and electrically charged dust (left), and unmagnetized and electrically charged dust (right).

Figure 1 shows the magnet technique performs better under highly magnetized dust, being useless otherwise. Airbone dust is thought to be mainly magnetized. Note also that even under favourable magnetized dust, the magnet technique exhibits saturation under certain levels of dust deposition.

In this paper We present an active dust removal technology based on a brush made of microfibers. This approach was finally selected due to the following:

1. Dust wiping using a brush guarantees a maximum lever of dirt on the wiped surface independently of the environmental conditions.
2. Dust wiping effectiveness does not depend on the type of dust particles (magnetized or unmagnetized), particles size, or deposition rate.
3. Dust wiping exhibits a dual functionality, since as it is shown further in this document, It also allows removal of frost.

2. TECHNOLOGY DESCRIPTION

Developed dust wiper technology consists of three main elements:

- The brush, designed and constructed from Teflon, Titanium, and Kapton.
- The actuator. Conventional motors could not be employed due to the strong requirement of minimizing mass. Therefore, a rotary actuator with a dynamic range of 43º was developed. The device is based on Shape memory alloy, it does not require lubrication, and it is immune to dust. Ultra-light structural materials are included in the design resulting in an extremely light but robust actuator. Since only two positions are demanded to the actuator (move to 43ºduring wiping, and remain in 0º during standby), control algorithm is very simple.

- The brush cleaners. Note dust is not destroyed but displaced. In this sense, brush cleaners were included in order to avoid saturation of the brush due to dust accumulation after multiple dust wiping operations. Several geometries were tested. The brush cleaners where optimized to the diameter of the brush fibers in order to ensure a correct cleaning of the brush. Microreplication was applied on the surface in order to guarantee an optimum removal of dust on the brush fibers.

Dust Wiper Technology was optimized to be implemented on MSL-REMS UV sensor. This implies wiping less than 30 cm^2 surface. To this end, a brush (Fig 2) of 65 mm was developed. Wiper manufacturing process was optimized and automated. In the order of 100 brushes were manufactured and after a screening process the best were chosen.

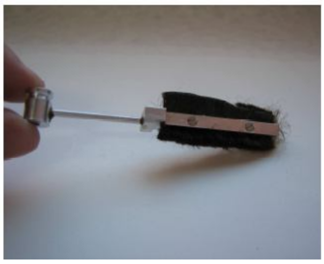

Fig 2. Wiper included multiple fibers arranged in order to achieve the wiping of submicron particles.

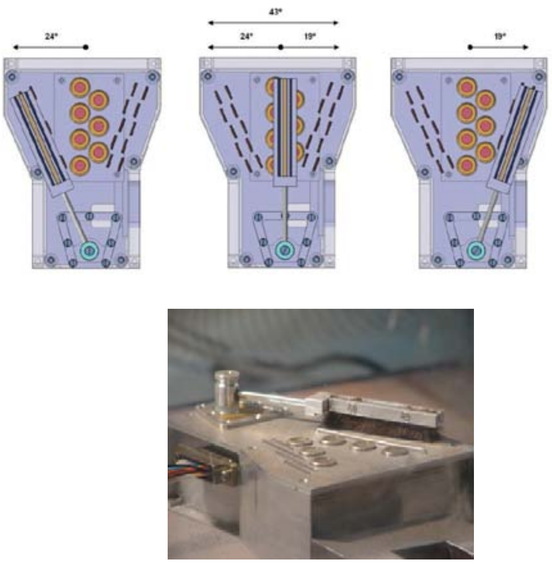

Fig. 3 (Top) Diagram of the rotary displacement of the wiper. (Bottom) Picture of the UV sensor with Dust wiper mechanism EM model.

3. FUNCTIONAL TESTS SETUP

Functional Tests of the technology were conducted using dust powders of less than 5 micron diameter, and a similar composition to that of Martian dust. In order to simulate the airbone dust deposition found in Mars, an environmental test chamber so called Martian Dust Simulation Chamber (MDSC) was developed. The chamber allows reproducing the process of airbone dust deposition in Mars by creating an airbone dust cloud inside the chamber. The cloud is created upon activation of the chamber air pump and the dust injector. The dust injector allows charging the injected dust by means of high voltage field. Once the cloud is created, the user must wait a few seconds in order for the airbone dust to settle on the bottom of the chamber, were the prototype under test rests. This way, dust deposition simulates the process of Martian dust deposition.

A UV source was place on top of the chamber in order to stimulate the UV sensor before and after dust deposition. It is used as reference to quantify the amount of deposited dust on the sensor. Humidity inside the chamber can be controlled in a range [10%RH-100%RH]. Air pressure and temperature are not controllable but measured.

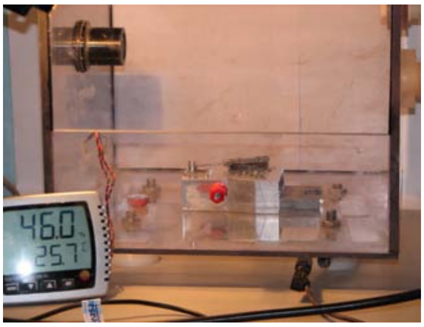

Fig 4 . Martian Dust simulation chamber (MDSC). CAD Diagram (Left), and prototype during test campaign (right)

In order to quantify the dust and powder removal from the surface it is defined a factor called the *cleaning efficiency* (CE) (1), which gives the percentage of the powder that has been removed after one dust wiper operation.

$$CE = \frac{I_f}{I_i} \times 100 \qquad (\%) \tag{1}$$

where:

- I_f is the signal received by the optical sensor after one dust wiper operation

- I_i is the signal received by the optical sensor when there is no dust deposited on its surface (perfectly clean)

Note the amount of deposited powder is measured by means of the optical signal received by the UV sensor. During the experiment the UV-light emits with a constant power.
In previous works [9] deposited dust quantity was measured by means of the mass. Nevertheless, during test phase we found dust mass is not quite representative of its perturbation on the optical signal (optical blockage). According to our measurements, dust optical blockage not only depends on dust mass but also on dust distribution. In this sense, it seems more adequate to measure the effective optical blockage of the dust.
Composition and grain size of the powders used during the test is similar to that of Martian dust. Grain size was selected to be less than 10 micron size. It was observed during the tests, that due to electrostatic forces between charged particles, agglomeration occurs, and dust particles much larger than this deposit on top of the sensor.

4. FUNCTIONAL TESTS RESULTS

Functional tests were first conducted under ambient atmosphere and temperature. By means of the Martian Dust Simulation Chamber CE coefficient was measured on 5 of the optical sensors distributed along the surface under consideration. Dust wiper performed with a similar efficiency regardless the position of the sensor. Tests were conducted at different dust deposition levels. In Figure 5, it can be shown the performance of the dust wiper under severe deposition level. It can be shown the brush cleaners effectiveness.

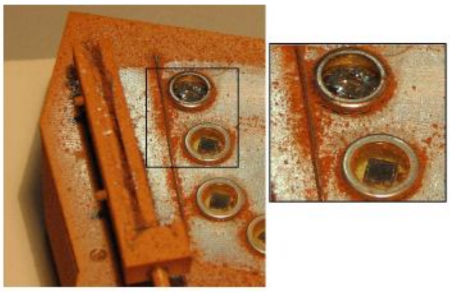

Fig 5. UV sensor with Dust Wiper EM model in action under high dust concentration. It can be shown that the dust is removed from the UV sensors.

In this sense, dust wiper system proved to be a useful tool not only for dust removal, but also as a method to uniform the deposited dust. In Figure 6, It can be shown that the technology allows a cleaning efficiency above 93% under worst case dust deposition conditions.

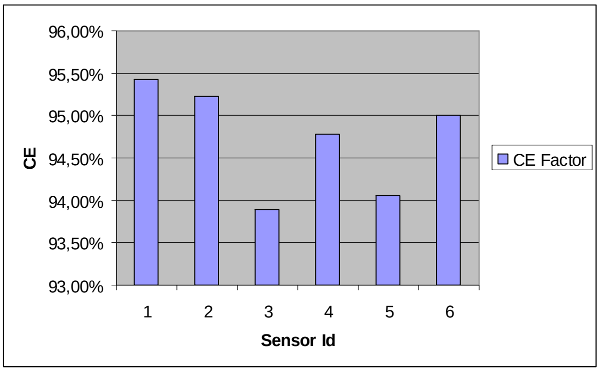

Fig. 6. Cleaning Efficiency measured through the CE coefficient at each sensor using one dust wiping operation under severe deposited dust conditions.

5. THERMAL TESTS RESULTS

Functional tests where conducted at -150ºC at Earth atmosphere. Due to the concentration of water vapour in the test atmosphere this caused the formation of frost on the sensor, serving also as a functional test of the device in relation to the removal of frost. It can be shown in Fig 7. that the device operates also as a frost removal.

Fig 7. Dust Wiper operating at -150ºC during qualification campaign showed successful performance in the removal of frost, increasing the range of applications of the technology.

Thermal cycles where also applied to the EM prototype in order to pre-qualify it for MSL mission. Cycles from -150ºC to +70ºC, with a ramp of 20ºC per minute where conducted. The device proved to operate perfectly after such thermal stress, even under ambient pressure, (in this case more stressing than Martian pressure).

The technology is radiation hard, no radiation tests were necessary since it was possible to justify by analysis.

Mechanical robustness according to mission requirements was demonstrated by analysis, and does not seem to be a source of problems due to the low mass of the device and dumping nature of the brush in regards to vibration.

6. CONCLUSIONS

In this paper, a robotic dust wiper technology is presented. The device is designed to clean surfaces from deposited Martian dust particles. This device may have further cleaning applications (solar panels, sensors, cameras, windshields etc), and in particular it may be useful whenever a robust cleaning mechanism is needed, and it is required to operate in human hostile conditions. In this case, the technology has been optimized to clean the surface of optical UV sensors.

The dust wiper technology is used to guarantee a maximum amount of deposited dust on the sensor. We quantify the cleaning efficiency by measuring the UV sensor signal before and after dust wiping under sever dust deposition and constant illumination. Cleaning efficiency above 93% was demonstrated by testing the device in a Martian Dust simulation Chamber (MDSC) specially constructed for this project. This implies the Robotic Dust Wiper allows educing the error of the sensor due to dust deposition down to 7%.

High performance brush was developed and included in the design of the wiper. The brush proved to be able to remove the micro dust particles such as the one expected in Mars. With a minimum impact on Mass, the robotic dust wiper is an appropriate technique to reduce the impact of dust on Martian operated instruments.

7. ACKNOWLEDGeMENTS

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