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Mars Dust-Removal Technology

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The Mars atmosphere contains a significant load of suspended dust. Settling of atmospheric dust onto the surface of the solar array is potentially a lifetime-limiting factor for a power system on any Mars mission. For long-term operation of arrays on Mars, it may be necessary to develop techniques to remove deposited dust. Dust is expected to adhere to the array by Van der Waals adhesive forces. These forces are quite strong at the dust particle sizes expected. If the array surface is insulating, it is possible that they may also be subject to electrostatic adhesion, which may be extremely strong. Dust-removal methods must overcome this force. Dust-removal methods can be categorized briefly into four categories: natural, mechanical, electromechanical, and electrostatic. The environment of Mars is expected to be an ideal one for the use of electrostatic dust-removal techniques.

Introduction

PRESENT and future missions to the surface of Mars are expected to use solar arrays for primary power, and there is some interest in characterizing the environment of Mars to model its effect on solar power production.[1–3]

The atmosphere of Mars is known to contain a significant load of suspended dust. This atmospheric dust will have several effects on the use of photovoltaic power systems on the surface, including decreasing the amount of sunlight on the surface and shifting the spectrum of the available sunlight.

There are several mechanisms for sand and dust to be deposited on a solar array. Particles may accumulate on the array by the process of saltation, the lifting of particles by wind. On Mars, the particle sizes most easily lifted by wind have a range of 50–100 μm in radius and, hence, are best referred to as fine sand. The trajectories average a height of 10–20 cm off the surface.[4] At the Mars atmospheric pressure of about 10 mbar, saltation occurs at wind velocities over about 15 m/s,[4] a wind velocity only seen during brief gusts at the Viking lander sites.[5] To avoid coverage of the array by saltation, it is desirable to design the arrays to be at least 20 cm from the surface.

It is expected that atmospheric dust will settle out of the atmosphere. The rate and mechanism of settling are not well characterized, but estimates indicate that obscuration of an array surface by dust may cause between 22 and 89% degradation in performance over the course of a 2-year mission[6] (Table 1).

Some information on the settling of dust will be generated by the materials adherence experiment on the Mars Pathfinder mission,[7,8] but the deposition rate is expected to be both geographically variable and to vary from season to season and from year to year.

If dust deposits onto the solar array of a Mars power system, what steps can be taken to mitigate the obscuration for long-term operation? This is potentially a lifetime-limiting factor for a power system on Mars, unless a technique is developed to remove the dust. Dust will be expected to adhere to the array by Van der Waals adhesive forces. These forces are quite strong at the dust particle sizes expected. If the array surface is insulating, it is possible that we may also find electrostatic adhesion (static cling), which is extremely strong. Dust-removal methods must overcome this force.

The removal by wind of deposited dust was studied under Mars conditions by Gaier et al.[9] The low atmospheric pressure on Mars means that a higher wind velocity (compared to terrestrial conditions) is required for dust to be removed from a surface by wind clearing. Gaier et al.'s[9] experiments show that a wind velocity of at least 35 m/s was required before significant amounts of dust removal were achieved by wind. Measurements of surface winds were done at both Viking landing sites. The daily peak wind was about 7 m/s at the Viking-1 site and about 3.5 m/s at the Viking-2 site. Winds over 15 m/s occurred less than 1% of the time. Over 100 days of operation, the peak gust velocity observed at the Viking-1 site was on the order of 25 m/s. Thus, these experiments suggest that it is unlikely for significant amounts of dust to be cleared from the array surfaces by wind. However, it was observed by Viking that the light surface coating deposited on rocks after the major dust storms (attributed to fine dust coverings) disappeared with time, indicating removal of the dust layer by wind. This indicates that it may be possible for some clearing of array surfaces to occur, possibly by the peak winds during brief gusts.

Gaier and Perez-Davis[10] concluded that wind-borne dust would not pose an abrasion hazard to arrays. These tests imply that wind removal may not be sufficient, and long-duration missions may require the periodic removal of accumulated dust to maintain solar-array power output. There are many possible ways that this may be accomplished. For manned missions, dust removal may be accomplished by an astronaut during extravehicular activity, i.e., manually dusting the arrays at intervals of several months. For designs similar to the Pathfinder solar array design, dust removal could be accomplished by using the array deployment motor to rotate the array petals into a vertical position during a period of light winds, so that wind-induced vibrations can shake adhered particles free. A brief discussion of dust removal can be found in Ref. 6.

Survey of Dust-Removal Methods

Dust removal methods can be categorized briefly into four categories: 1) natural, 2) mechanical, 3) electromechanical, and 4) electrostatic.

Natural Dust Removal

For Mars, the only significant category of natural dust removal is wind clearing. As discussed in the preceding text, wind clearing does not seem likely to be applicable for hori-

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Table 1 Calculated power loss of solar array caused by settled dust for missions on Mars[6]

	Obscuration, %	
Case	30-day mission	2-yr mission
Baseline	6.6	77
Best	0.5	22
Worst	52.2	89

zontal arrays at locations with wind conditions similar to those found at the Viking landing sites. Other sites could have periodic winds that are higher (although it should be noted that selecting a site for high winds will probably be contraindicated for other reasons). Gaier and coworkers also tried using obstacles to make the wind flow turbulent, without great success in dust removal.[9,10]

It is possible that by simply choosing an array orientation other than horizontal, dust will not effectively stick to the arrays. As the dust settles, there will be microscopic wind motions and, if the array is tilted, the bias effect caused by gravity may mean that the dust will move down the array, and thus not effectively stick. For example, dust did not accumulate on the vertically oriented camera window of Viking, and thus we know that we can use a vertically oriented solar array and expect no dust obscuration.

A possible dust-removal strategy would be to use an articulated array that is periodically rotated into a vertical orientation for dust removal. This could be done with the motors used to deploy the array or by the tracking system, for an array incorporating solar tracking. It is unlikely that reorientation alone will be effective enough to remove adhered dust, because the adhesion forces of the dust are expected to be significantly higher than gravitational forces, but in a vertical position it should be expected for wind to cause the array to shake. This may cause adhered dust to be vibrated loose and removed. This removal strategy could be done during morning or afternoon periods when the sunlight is horizontal, or during the night, when array orientation is irrelevant.

Even for a horizontal array, such as the Surveyor lander, wind-induced shaking of the array might result in dust removal. This will depend on the stiffness of the array, the natural frequency, and the interaction of the array with the wind. It might be desirable to deliberately design an array with an easily excited natural vibration frequency that would cause dust to be removed.

Mechanical

The category of mechanical dust removal comprises physically clearing the surface using mechanical wiping, blowing, or removable covers.

Dry mechanical wiping could be accomplished by astronauts using a tool designed for the task, effectively a broom or feather duster to break the dust adhesion. The dust adhesion is likely to be high enough and the particles small enough that a simple windshield wiper will probably not be effective. For an unmanned probe, a mechanical tool in the form of a mechanical arm with a rotating whisk on the end could be designed, but such a tool would probably be heavy and unreliable.

A lubricated windshield wiper or cloth would be preferable. This is, of course, the system used on Earth in automobile windshield washers and for cleaning building windows. Designing such a system would require investigating fluids that remain liquid at the cold martian temperature and low atmospheric pressure. If such fluids could not be easily replaced with in-situ resources, the cleaning fluid would have to be brought from Earth. Water might be extracted from the atmosphere, for example, by the operation of a sorption pump, and if the array is warm enough, this could be a possibility. Some processes proposed for the production of rocket fuel on Mars involve the capture of water from the atmosphere or out of permafrost; if such a system is used, a small amount of the water may be available for use as a cleaning agent. Because the ambient atmospheric pressure of Mars is low enough that liquid water is not present in an equilibrium state, use of water as a cleaning agent would have to be done quickly.

The Viking lander included a system where a compressed jet of gas could be directed to the window. Such a system could be designed with either a canister of gas brought from Earth, with a gas reservoir refilled from a compressor operating on the ambient atmosphere, or with a set of fans. Jets of atmosphere could easily be designed to locally exceed the 35 m/s velocity estimated by Gaier et al.[9] to remove dust.

Finally, for the case where the effect of a single dust event (or a small number of dust events) must be mitigated, it would be possible to use a simple transparent cover over the array, which could be removed and discarded after the dust event. The cover could be a simple sheet of a thin plastic such as mylar. This might be a reasonable approach, for example, if a lander is to be designed to survive a single Mars year, and the deposition of one global dust storm is to be accounted for. If a plastic is chosen for this use, it will be necessary to qualify the material for operation under the combined uv, radiation, and chemical conditions of Mars to verify that it will not degrade in either mechanical or optical properties.

Electromechanical

Electromechanical methods include shaking the array, shocking the array, or using sound or ultrasound to break dust adhesion. These are similar to the natural removal techniques discussed earlier. They will probably require either wind or tilting the array to carry the dust away after adhesion is broken.

Electrical

The simplest of the electrical removal methods is electrostatic removal. If the array surface is charged, the array will attract particles of opposite or neutral charge and repel particles of the same charge. If the surface is conductive enough to be able to transfer charge to the particles on contact, any dust particle in electrical contact with the surface will accumulate a charge the same as that of the array, and thus be repelled from the array. They could then be removed either by wind, tilting the array, or by providing a sink of opposite charge for them to be attracted to. The array could be charged by incorporating a transparent conductor on the surface and temporarily charging the array with a high-voltage supply. An alternative would be to use an ion- or electron-beam or a radioactive source to charge the surface remotely, if this can be done at the atmospheric pressures to be encountered. Yet another alternative might be to use the photoelectric effect to charge the surface, possibly incorporating a material that will charge in the natural solar uv environment.

An alternative solution would be to use electrostatic forces to not allow the dust to deposit in the first place. If Mars dust particles have a natural charge, for example, induced by photoelectric effect, this could be done by simply placing a like charge on the array. However, because charging of either polarity will attract neutral particles (by induced-dipole attraction), this is not likely to be a solution. A charged body near, but not on, the array might be used to attract particles away from the array. Electrostatic forces could also be used to create an atmospheric flow over the array. Finally, an electrostatic discharge (glow discharge, Paschen discharge) could be created over the array. This might be made to result in dust removal by charging the dust or even, conceivably, by glow-discharge cleaning.

Discussion

Of these alternatives, the one most likely to be implemented in a transparent fashion, that is, with a negligible mass impact and without any impact on other mission activities, is electrostatic dust removal. This has been used on telescope mirrors to keep dust out during manufacture; it also seems to be the operating principle for dust-removal guns for phonograph records. If this can be demonstrated to work under Mars conditions, the more complicated methods would be superfluous.

The environment of Mars is expected to be an ideal one for use of this electrostatic dust-removal technique. Because the atmosphere is cold and dry, it is an excellent place to use techniques that utilize electrostatic charge. The limit of voltage that can be applied is set by the breakdown of the Mars atmosphere by Paschen discharge.[11] An experiment for the 2001 Surveyor Lander mission will test the use of electrostatic dust removal on Mars.[12] The flight package will also carry a sensor package[13] to gather engineering data about the deposition rate and properties of the dust.

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