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Paper Session II-A - Electrodynamic Shield to Remove Dust from Solar Panels on Mars

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Abstract

The Materials Adherence Experiment on the Mars Pathfinder mission measured an obscuration of the solar arrays due to dust deposition at a rate of 0.28% per day. Dust deposition is the prime mission constraint of the duration for the current Mars Exploration Rovers which are expected to last around 90 sols. Here we have developed a prototype Electrodynamic Shield to be used to remove dust from solar panels on Mars. This technology, developed in the 1970's, has been shown to lift and transport charged and uncharged particles using electrostatic and dielectrophoretic forces. This technology has never been applied for space applications on Mars nor the moon due to electrostatic breakdown concerns. However, we show that using an appropriate design not only can the electrostatic breakdown be prevented, we are also able to show that uncharged dust can be lifted and removed from surfaces under simulated Martian environmental conditions. This technology has many potential benefits for removing dust from visors, viewports and many other surfaces as well as solar arrays.

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Abstract

The Mars Opportunity rover in the current Mars mission has measured an obscuration of the solar arrays due to dust deposition at a rate of 0.15% per day. Dust deposition is the prime mission constraint of the duration for the two rovers operating now on Mars. At the Kennedy Space Center, we have developed a prototype Electrodynamic Shield to be used to remove dust from solar panels on Mars. This technology, developed in the 1970's, has been shown to lift and transport charged and uncharged particles using electrostatic and dielectrophoretic forces. This technology has never been applied for space applications on Mars nor the moon due to electrostatic breakdown concerns. However, we show that using an appropriate design not only can the electrostatic breakdown be prevented, we are also able to show that uncharged dust can be lifted and removed from surfaces under simulated Martian environmental conditions. This technology has many potential benefits for removing dust from visors, viewports and many other surfaces as well as solar arrays.

1. Introduction

It has been estimated that settling dust may cause degradation in performance of a solar panel of between 22% and 89% over the course of two years [1, 2]. These results were obtained without the presence of a global dust storm.

Several types of adherence forces keep dust particles attached to surfaces. The most widely discussed adherence force is the electrostatic force. Laboratory experiments [3] as well as indirect evidence from the Wheel Abrasion Experiment on Pathfinder [4] indicate that it is very likely that the particles suspended in the Martian atmosphere are electrostatically charged

2. Electrodynamic Dust Shield

Masuda and collaborators at the University of Tokyo developed a method to lift and transport particles called the *electric curtain*, in which a series of parallel electrodes connected to an AC source generate a traveling wave that acts as a contactless conveyor [5-8].

We have developed an Electrodynamic Dust Shield prototype to remove dust from surfaces using electrodes that are alternately connected to an AC source and to ground. The electrodes are embedded in a transparent dielectric film to decrease their breakdown potential. Several prototype shields have been tested to check the cleaning efficiency as a function of various line widths and spacings. We used square waveforms in which the frequency was varied from 0 to 500 Hz and the voltage was varied from 0 to 10 kV [9].

Experiments under terrestrial environmental conditions were performed with a screen with 0.7 mm thick electrodes at a spacing of 1.5 mm. The screen was coated with two thin coats of polyurethane in order to prevent spark discharge. A thin coating of the JSC Mars-1 Martian simulant [10] was deposited onto the prototype shild. The simulant dust was baked out at 150°C for several days to remove moisture and the particle sizes were less than 50 μm in diameter. About 4000 Volts (peak-to-peak) at 500 Hz was applied to the screen to remove the fine adhesive dust. Dust removal was observed at voltages as low as 800 V_{p-p} under ambient (Earth) conditions.

Fig. 1 shows the dust-laden Electrodynamic Dust Shield before and after the voltage was applied. Application of the AC field showed that positively charged particles moved to the left while negatively charged particles were deposited to the right of the screen. A short movie of this experiment is located at: http://physics.ksc.nasa.gov/CurrentResearch/ElectrodynamicScreen/Electrodynamic.htm

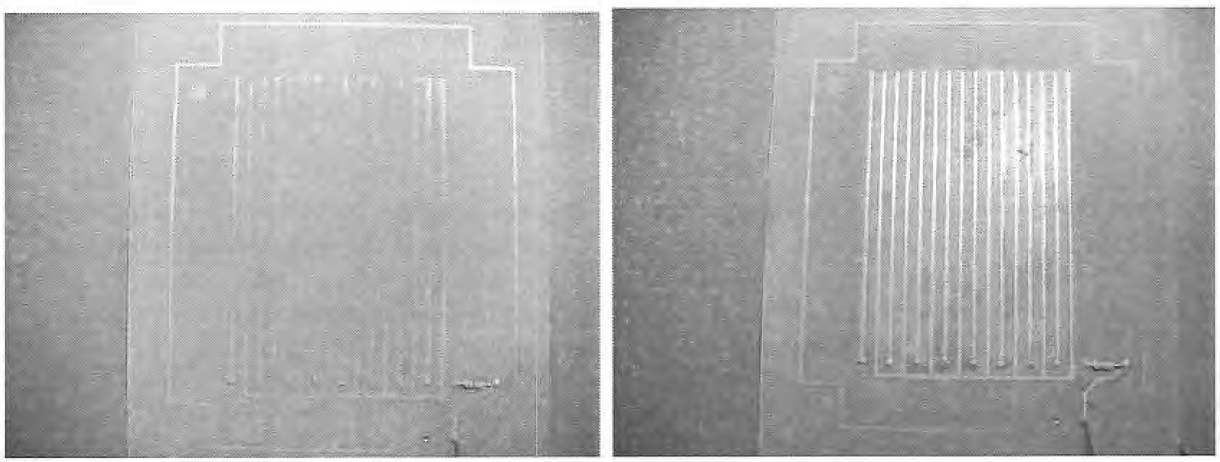

Figure 1. (top) The dust-laden screen before the voltage was applied and **(bottom)** dust removal afterwards. This experiment was performed at terrestrial environmental conditions.

3. Experiments Under Simulated Martian Pressures

Further experiments using various spacings and widths are shown below. Figure 2 shows the minimum voltage amplitude (square wave) required for particle transport as a function of frequency for three screens at both atmospheric pressure and simulated Martian pressures of 7 torr CO_2 The voltage values for particle movement at atmospheric pressure are consistent with the literature [8] with lower voltages required for lower frequencies. It is well known that the lower pressure of the Martian environment is conducive to electrical breakdown due to Paschen's Law, which limits the strength of the electric field allowed between two conducting surfaces. Therefore, experiments were designed to check the feasibility of using this approach under Martian conditions. We present the results for the Electrodynamic Dust shield at low pressures in CO_2.

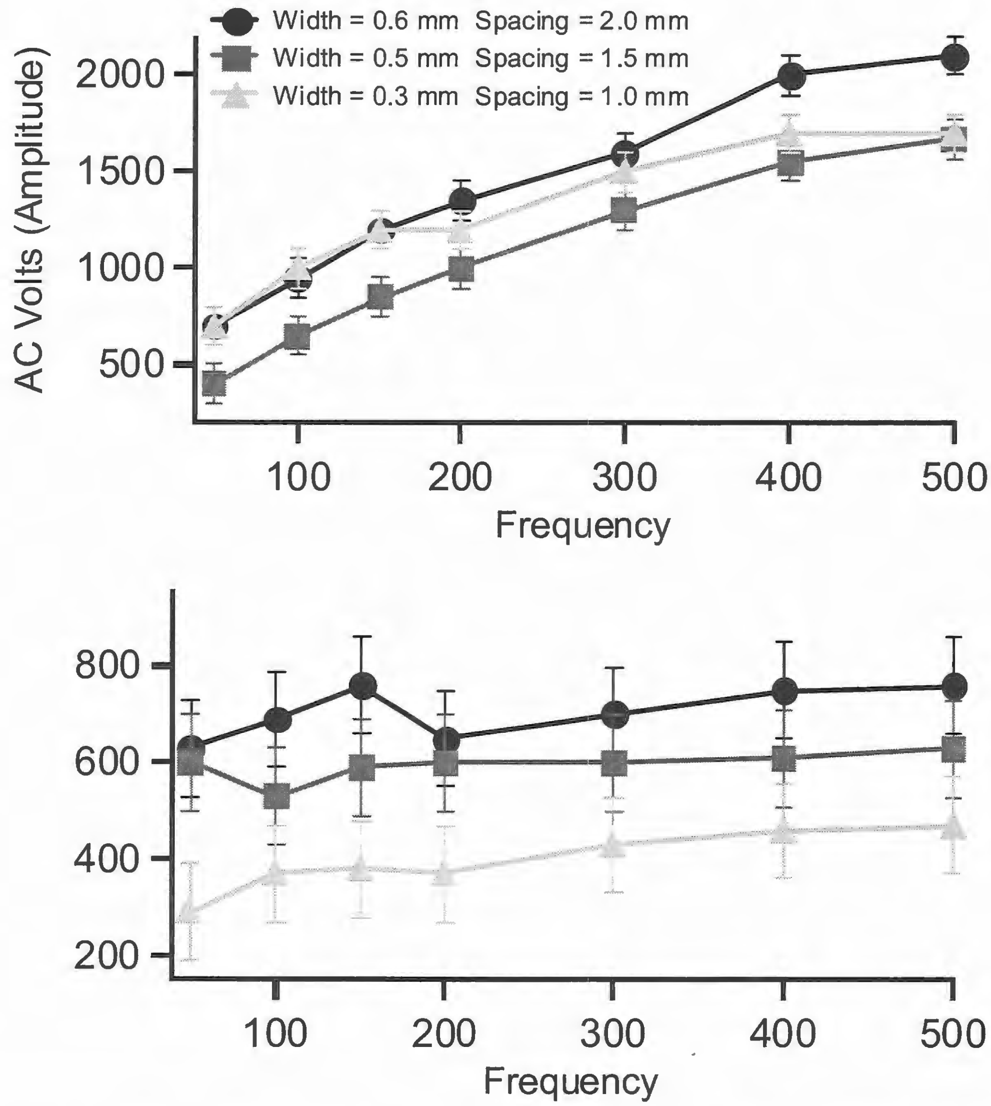

Figure 2. The minimum voltage required for particle transport as a function of frequency for screens of various widths and spacings at (top) atmospheric pressures and (bottom) at simulated Martian pressures 7 torr CO_2.

At lower pressures (Fig. 2, bottom), the Electrodynamic Dust Shield performed extremely well. The voltages required were very low and the efficiency was not a strong function of the frequency. Much lower voltages were required for transport and the cleaning efficiency was enhanced. Due to the much lower atmospheric pressure on Mars the initial change in momentum of the dust particles is greater. As a result, smaller electrostatic forces (lower electrode voltages) are needed to lift and move these dust particles. The weaker gravity on Mars should also aid in the removal process. The electrical breakdown of the gas did not occur until the amplitude of the potential exceeded 800 volts (1600 V_{p-p}) with the three prototype screens.

The dust deposition depended highly on the spacing and width of the screen. For the largest spacing (black line in Fig. 2), the particles deposited in the region between the electrodes, while the smaller spacing (red line) deposited the particles onto the grounded electrodes. Complete removal was not obtained (with this signal-phase signal) until the spacing was down to 1.0 mm (green line) for the given signal. For continuous operation, the prototype screens were 5 × 10 cm in size and required less than 0.02 W/cm^2 when activated. On Mars, this system will be activated only when dust removal is required, perhaps once a sol. Therefore, the daily power requirement will be relatively low. In these experiments, we completely covered the screens with approximately 0.5-1.0 grams of simulant, far more than the expected 30,000 particles per cm^2 [11].

Preliminary results with these unoptimized screens indicate that this technology can be applied under Martian conditions without electrostatic breakdown problems. Furthermore, the low voltages and frequency requirements should not pose serious power, mass or safety concerns for future space vehicles.

References

[1] Landis, G.A., *Acta Astronautica*, **38**, No. 1, 885 (1996).

[2] Landis, G.A. and Jenkins, P.P., *JGR*, **105**, 1855 (2000).

[3] Calle C.I., J.G. Mantovani, C.R. Buhler, E.E. Groop, M.G. Buehler and A.W. Nowicki, *Proc.of the ESA-IEEE Joint Meeting on Electrostatics*, Laplacian Press, Morgan Hill, CA, pp. 90 (2003).

[4] Farrel, W.M., M.L. Kaiser, M.D. Desch, J.G. Houser, S.A. Cummer, D.M. Wilt, and G.A Landis, *JGR*, **104**, 3795 (1999). [5] Masuda, S., *Advances in Static Electricity*, **1**, Auxilia, S.A., Brussels, 398 (1970).

[6] Masuda, S., *Proc.of Albany Conference on Electrostatics*, (1971).

[7] Masuda, S. Fujibayashi, K., Ishida, K., and Inaba, H., *Electronic Engineering in Japan*, **92**, 9 (1972). [8] Masuda, S., and Matsumoto, Y., *Proc.of the 2nd International on Static Electrification*, Frankfurt (1973).

[9] Sims, R.A., Biris, A.S., Wilson, J.D., Yurteri, C.U., Mazumder, M.K., Calle, C.I., and Buhler, C.R., *Proc.of the ESA-IEEE Joint Meeting on Electrostatics 2003*, Laplacian Press, Morgan Hill, CA, 814 (2003a

10] Allen, C.C., Jager, K., Morris, R., Lindstrom, D., Lindstrom, M., and Lockwood, J., *Proc.of the Conference American Society of Civil Engineers*, Albuquerque, NM, 469, (1998). [11] Landis, G.A., *Acta Astronautica*, **38**, No. 1, 885 (1996).