# Development of a Transparent Self-Cleaning Dust Shield for Solar Panels

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***Abstract*— Development of a transparent electrodynamic shield to protect panels from dust deposition is described. The shield contains a clear panel with embedded parallel electrodes connected to a single-phase AC supply for producing an electromagnetic wave. The electromagnetic field produced by the electrodes on the surface of the panel repels dust particles that have already deposited on the panel surface, and prevents the deposition of further particles if they are charged with positive or negative polarities. If the particles are uncharged, they deposit on the surface of the panel momentarily, but are then subjected to an in-homogenous electric field, and move across the surface of the panel. This motion of the particles causes them to become triboelectrically charged, and the electromagnetic field then ejects them from the surface of the shield. A brief review of the previous studies on the development and application of electromagnetic screens is presented. The current research focus is on applying these screens to: (1) protecting solar panels, and (2) developing an aerosol holding chamber in which a cloud of charged particles can be introduced and sampled without significant loss of the particles on the walls of the chamber. The characteristics of the flat panel as well as the performance of a screened holding chamber for charged particles will be reported with experimental data.**

## I. Introduction

In a number of applications, especially in dusty environments, it is required for surfaces or walls to remain free from airborne particle deposition. A typical example is the deposition of dust on the solar panels or windshields in arid and dusty zones. The dust reduces the power generated by the solar devices or hinders the visibility through windshields. Another example is in containers of airborne pharmaceutical powders. These powders have a high cost per unit mass. Given that up to 20 % of these powders could deposit on the walls and potentially be lost, a technology to reduce this deposition would be highly beneficial.

Also significant work has been done by Masuda et al [1] in transporting blood cells and other biological matter in liquids by using uniform or nonuniform traveling fields. Different types of cells can be separated using this technique. A similar application presented by Moesner is to move fluids through microchannels [2], a process that is improved by using electrical fields.

Other applications require the transportation of solid matter inside tubes [3] by a carrier gas or liquid flow. The particles, suspended in the fluid get charged due to the tribocharging mechanism. Electrodes connected to an AC power supply are applied on the exterior of the tube generating a moving electrical field that entrains the particles inside the tube.

The application being reported on here is the development of a transparent shield, which when placed on top of a solar panel or a windshield does not allow solid microsized particles to deposit. The shield, using the technique traveling electrical fields will keep them clean for long periods of time. There is no mechanical movement to scratch the protected surface, which would reduce the transparency. This paper analyzes the factors that influence the cleaning process and the overall performance of the shield.

## II. Theoretical Discussions

The principle of the moving electrical fields for transportation of particles was first reported almost twenty years ago [4,5]. The transport of particles along the surface of the solar panel, requires an AC electric field which generates high-voltage polyphase waveforms at various frequencies. Under the right frequency and amplitude conditions, the charged particles will not be allowed to deposit, but will be entrained to move along the surface following the electric field. In this way, the surface will stay clean of particle deposition.

Masuda [1,6] discusses the motion of particles along a surface. It was shown that for a single order electrical field, which produces two main forces that act upon a particle:

1. the transportation force, in a direction x along the surface and
2. the repulsion force, normal to the surface;

These electrical forces are given by:

$$F_x = \frac{9}{4}\alpha\frac{6\pi\eta a}{\omega}\left(\frac{q}{6\pi\eta a}E_0\right)^2 \exp(-2\alpha x) \quad (1)$$

$$F_y = \frac{9}{4}\alpha m\left(\frac{q}{6\pi\eta a}E_0\right)^2 \exp(-2\alpha x) \quad (2)$$

where q is the particle charge, a is the radius of the particle, $\eta$is the viscosity of air, $E_0 = \alpha\phi_0$, where $\phi_0$ is the potential at the initial moment.

In the horizontal direction there is also the drag force and for the vertical direction there are gravitational and drag forces The equations of the particulate motion can be written as:

$$6\pi\eta a\frac{dX}{dt} = F_x \quad (3)$$

$$6\pi\eta a\frac{dX}{dt} = F_y - \left(\rho - \rho_0\right)V_P g \quad (4)$$

where $\rho$, $\rho_0$ are the density of the particles and the airrespectively, and $V_P$ is the volume of the particle. These equations describe the motion of the particles under the traveling electrical fields. The repulsion force is responsible for levitating the particles from the surface of the shield, while the transportation force is responsible for the horizontal motion of the particles. These forces overcome the adhesion and gravitational forces that also act upon the particles. As seen from equations 3 and 4, the strength of the two motion forces is proportional with the applied voltage to the shield. Therefore, by finely tuning the voltage amplitude, it is possible to remove particles with a wide range of sizes. The velocity of the particles along the shield depends upon the frequency of the electric field and the gap between the electrodes.

Although the forces responsible for the motion of the particles depend on the their charge, uncharged particles will ultimately be removed from the shield. The explanation is given by the fact that once the particles touch the surface of the shield they will get charged due to tribocharging. The level of charge can further increase if the particles roll, slide, vibrate or collide against the surface several times. The charge acquired also depends upon the work function of the two materials, the humidity and other external parameters. The maximum charge a particle can get through tribocharging is given by:

$$Q=\varepsilon_0\pi d^2 E_I \quad (5)$$

where $E_I$ is the break down field.

## III. Construction of the Dust Shield

The shield consists of parallel lines etched on a clad board. Every other lines are connected together like in the schematic shown in Fig.1. The AC voltage

and frequency applied between the two sets of lines was varied in order to find the right values. Several shields with various line thicknesses and spacing were tested. The results presented in this work were taken with a screen that had 0.03" thick electrodes and a distance of 0.06" in between. The reason of changing these dimensions was to see their influence on the cleaning properties of the surfaces.

The waveform of the applied signal was also varied to study the effect. The different waveforms used were sinusoidal, square, triangular, and pulsed. The frequency was varied from 0 to 300 Hz, while the voltage was varied from 0 to 10 kV.

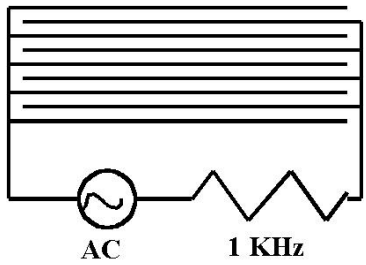


Fig.1. The schematics used for the electrodynamic screen

## IV. Results and Discussions

The electrical field distributions around the electrodes was modeled using Lorentz® 2D and are shown in Fig.2.

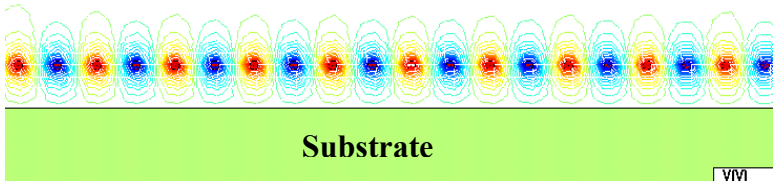


Fig.2. The electrical field distributions around the electrodes of the shield

The charged particles will levitate over the surface of the screen given the repulsion forces that oppose the gravitational forces. At the same time, the particles will move along the surface of the screen by following the change in the electrical field distribution. As mentioned before, the uncharged particles once will collide against the surface of the screen will get charged and will also be remove. In order to numerically compare the dust and powders removal from the screen it is defined a factor called the clearing factor (CF) and which gives the percentage of the powder that has been removed from the screen after each experiment.

$$CF = \frac{m_i - m_f}{m_f} X100 \qquad (6)$$

The voltage applied to the electrodes was found to have the most important effect upon the cleaning of the deposited powder particles. The problem which was encountered was that at high voltage values, there were electrical discharges and sparks between the electrodes. These sparks occurred at voltages of around 2 kV. Therefore in order to hinder the spark occurrence, the surface of the shield was covered with a thin layer of industrial grade polyurethane (PU). In this way, the electrodes were completely embedded in the highly resistive polyurethane coating. Once this procedure was done, there were no more electrical discharges observed between the electrodes, not even at high voltages of 10 kV.

The most important parameter to influence the clearing factor CF was found to be the voltage applied to the electrodes. Fig.3 shows the variation of the clearing factor with the voltage for different powders. There were chosen three different powders:

1. JSC-1 Mars dust simulant,
2. acrylic powder used in the automotive industry and
3. lactose widely used in the pharmaceutical industry.

Fig. 3 shows the variation of the clearing factor with the voltage for these three powders.

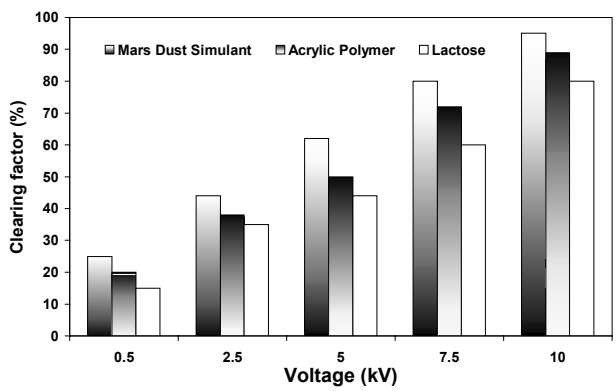


Fig.3. The clearing factor for different powders at various voltages

Fig. 3 shows that the Mars dust simulant has a very good clearing factor even at lower voltages, as compared with the other two powders. The lactose was also being cleaned from the panels, result that could be very important for the pharmaceutical industry. An interesting observation is that the frequency of the signal did not appear to influence too much the clearing fac-

tor. The frequency was only observed to be responsible for how fast the shield is cleaned. Fig. 4 shows the influence of the Q/M of the powder on the clearing factor.

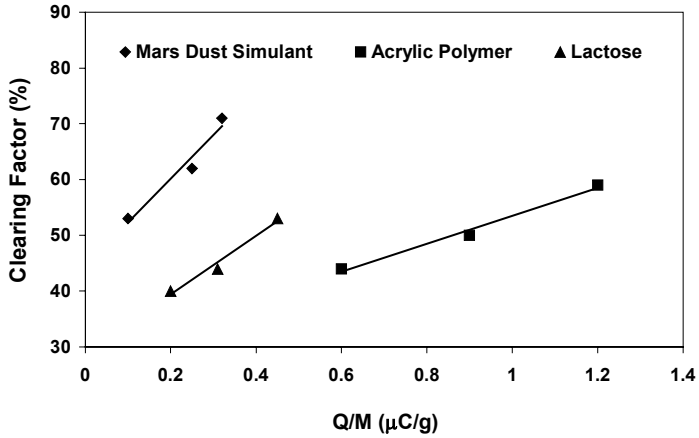


Fig.4. The variation of the clearing factor with the Q/M ratio of the powders. The voltage between the electrodes was kept constant at 5 kV, and the shape of the signal was square, at a frequency of 500 Hz

The more highly the powder is charged, the faster is removed form the shield. This fact can be explained by the correlation between the removal forces and the charge level of the particles. Obviously, particles with a low charge would take a longer time to be removed while levitated, since their motion will be much slower. In order for a particle to be very quickly removed, it has to hold the charge for the time it levitates over the shield. If the charge decays much faster, the particle will fall on the panels and will have to get charged again due to the contact interaction with the surface. Therefore the particles with high charge decay values, will take longer to be removed. The charge decay time constant is described by the charge decay time constant $\tau$, calculated form the charge variation over time:

$$q = q_0 e^{-\frac{t}{\tau}} \qquad (7)$$

The measured charge decay time constants for the three powders were: Mars dust simulant: about 5 min., acrylic polymer powder: about 150 min., and lactose: less than 2 min. Although the acrylic powder has the largest charge decay time constant, the powder that was removed the fastest eld was the Mars dust simulant.

The shape of the AC signal was also investigated. Three types of signal were applied: sinusoidal, square, and pulsed. The results are shown in Fig. 5. The

results are also supported by the visual observation. Most of the powder was removed when the AC signal that was applied to the electrodes was pulsed, on or off. The explanation is that for very short time periods, the removing forces are extremely intense (dependant on the rate of change of the signal), which would immediately levitate the particles and remove them from the shield.

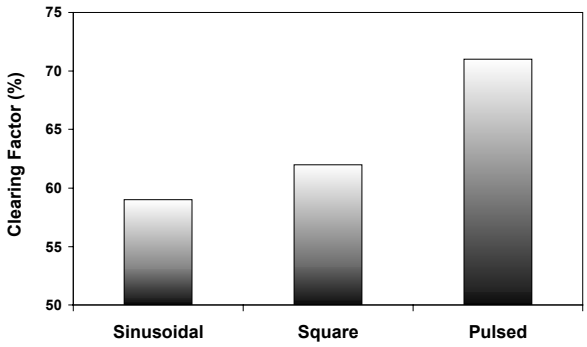


Fig. 5. The effect of the AC signal shape on the clearing factor

## V. CONCLUSIONS

A shield for preventing the dust or the airborne particulate from depositing on the surface of the solar panels or different surface was built and tested. It has parallel electrodes, and an AC signal with various amplitudes, shapes and phases was applied. The parameter that influences the most the clearing factor (the ratio of the powder removed during one experiment) was found to be the voltage. Even at low voltages the screen removed part of the dust, but as a general observation, the higher the voltage, the better the dust removing. Three powders were testes (Mars dust simulant, acrylic polymer powder and lactose). The results showed that the Mars dust simulant was the powder easiest to be cleaned from the shields. The frequency of the AC signal was not found to significantly influence the clearing factor, but it was responsible for the velocity of the particles along the shield surface. The shape of the signal that had the best clearing factor was the pulsed one.

## ACKNOWLEDGMENT

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