

In-Situ and Simultaneous Measurements of Size and Charge Distributions of Dust on Mars: Instrumentation and Analysis. M.K. Mazumder¹, C. I. Calle², P. K. Srirama¹, J. D. Wilson¹, J. Zhang¹, C. H. Buhler², and M. Ali¹
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Abstract: The atmosphere on Mars contains a substantial amount of suspended dust which settles on rovers, solar arrays, and spacecrafts. Martian dust characterization is important for minimizing the effects of abrasion, adhesion, corrosion, and damage to mission hardware, and also to reduce the effect on human health [1]. Mars has very low atmospheric pressure and low humidity as compared to that on Earth, which makes the dust on Mars more prone to contact charging and electrical discharges. In order to simultaneously analyze the particle size and charge on Mars dust particles a miniaturized version of the Electrical Single Particle Aerodynamic Relaxation Time (ESPART) analyzer, the Dust Particle Analyzer has been built and tested. The Dust Particle Analyzer (DPA) is based on a Laser Doppler Velocimeter (LDV) and heterodyning principles where the laser beams are frequency shifted by a rotating diffraction grating to generate a moving fringe pattern. The dust particles passing through the sensing volume of the LDV undergo oscillations depending upon the applied electric or acoustic sinusoidal excitations, and the measured particle size range is dependent upon the particle relaxation time and the excitation frequency. Mars dust simulant, JSC Mars-1 was tested extensively to show the capabilities of the DPA. The instrument was tested under Martian atmospheric pressure and gaseous conditions, to check the functionality and reliability of the instrument.

Introduction: *Mars Dust:* During human lunar missions, astronauts have reported that dust seeps into small crevices in their EVA suits leading to obstruction of movement [1]. Mars has a significant number of localized dust storms, referred to as dust devils which can attain heights of nearly 6 km [2]. Wind velocities on Mars have been studied to attain at least 32 m/s. Due to the nature of storms and other atmospheric activity, dust gets electrostatically charged due to contact charging and by photoemission. Mars has a very low atmospheric pressure (~ 5 -10 mb), and low humidity as compared to that on Earth, which makes the dust on Mars more prone to triboelectric charging and electrical discharges. Due to the low Martian atmospheric pressure and a lack of an ozone layer, the amount of UV radiation reaching the surface is high, which leads to photoionization of the dust particles which are suspended for long durations.

Particles which are about 50-100 μm in diameter are easily lifted by the Mars winds, but settling is faster. But smaller particles, approximately 1-5 μm in

diameter remain suspended for a long time [3], if they are dispersed into air. Atmospheric dust particles on Mars after settling may obscure solar panels, clog filters, valves, and mechanical devices, may deposit on electronic components and cause malfunction. Dust can adhere to solar, radiator, sealing, mechanical, and optical surfaces of future Mars missions leading to degradation in power generation, overheating of life-support systems, cause wear and tear of extravehicular activity (EVA) suits, and reduce performance of optical instruments. Electrostatically charged dust particles cause two major problems, (1) adhesion, between the particles and the substrate, increases significantly under dry conditions, and (2) deposition of particles increases as the charged particles seep into the recessed areas of equipment.

Challenges in remote in-situ measurements: One of the first steps to dust mitigation is to know the particle size and charge of the dust particles. Once these characteristics are thoroughly known, dust mitigation technologies can be more efficiently designed. Research into dust mitigation devices has shown that the size and the charge associated with the dust particles are both important in designing efficient dust removal technologies. An instrument is needed which will measure the instantaneous particle size and charge distributions on dust particles in real time, which will help in designing mission hardware to withstand the effects of adhesion, abrasion, corrosion and other related effects.

For any particle analyzer to function on Mars, many environmental criteria have to be considered. The atmospheric pressure on Mars is about a one-two hundredth of earth's atmosphere, and its atmospheric composition is mainly CO_2 . The atmospheric electrical breakdown is dependent on the atmospheric composition and pressure. On Earth, the electrical breakdown is of the order of 3000 KV/m whereas on Mars it is expected to be approximately 20 KV/m, which leads to frequent electrical discharges at lower voltages [4].

ESPART Analyzer: To measure simultaneously both particle size and charge in real time, the Electrical Single Particle Aerodynamic Relaxation Time (ESPART) Analyzer [5] had been developed at University of Arkansas at Little Rock over a number of years. The basic underlying principle of a ESPART analyzer is to measure the phase difference between the frequency of oscillation of a particle and the external field moving the suspended particle, and by calcu-

lating the relaxation time and the aerodynamic diameter from the measured phase difference with the computations made in real time. The range of size measured by the ESPART analyzer depends on the applied excitation frequency; a 1 KHz excitation would be suitable to measure particles in the 2 – 20 μm size range, whereas with a 20 KHz excitation, particles in the size range 0.2 – 2 μm could be measured. ESPART has been used extensively for measuring the particle size and the charge-to-mass ratio of toners and particles used for respiratory drug delivery.

For the ESPART analyzer to be utilized on Mars missions, a number of modifications were made. The electrical excitation voltage used to oscillate the particle had to be substantially lower to prevent breakdown between the electrodes. Also, low power consumption devices were used, since there is minimal power generated by the solar arrays on Mars spacecraft.

Theoretical overview: Particle Size and Charge Measurement. The ESPART analyzer uses the principle of Stokes' Law and Laser Doppler Velocimetry in determining the particle size and charge. As a particle travels through air it experiences a drag force which is proportional to the diameter of the particle, given by Stokes' Law [6, 7]. The drag force, $F_D = 3\pi\eta dV$, for a spherical particle if particle Reynolds number is less than one.

When a particle is subjected to an external force, the time required for it to attain its steady state is called the relaxation time. For sinusoidal external forces the relaxation time is related to the phase lag between the oscillation of the particle and excitation force. The aerodynamic diameter (d_a) and the electrostatic charge (q) of the particle when an external AC field ($E_0 \sin \omega t$) is applied is given as

$$d_a = \left(\frac{18\eta\tau_p}{\rho_0 C_c} \right)^{1/2} \dots(1)$$

$$q = \frac{V_p}{E_0} \frac{3\pi\eta d_a}{C_c} \sqrt{(1 + \omega^2 \tau_p^2)} \dots(2)$$

where η is the coefficient of viscosity in air, V_p is the velocity of the particle relative to the fluid, and C_c is the Cunningham Slip correction factor, τ_p is the relaxation time, ω is the frequency of excitation, and ρ_0 represents unit density 1000 Kg/m³. To find the charge on a particle the particle velocity V_p amplitude and the amplitude of the electric field E_0 has to be known.

Dust Particle Analyzer Design and Setup: One of the primary challenges in building an ESPART analyzer for Mars (Dust Particle Analyzer (DPA)) is to substantially reduce its physical dimensions, weight, and power requirements. The conventional ESPART analyzer utilizes a He-Ne gas Laser with a Bragg cell

and optics to generate the frequency shifted laser beams. For the DPA, He-Ne gas Lasers were replaced by Laser diodes which are substantially smaller. There are two methods for frequency shifting of the laser beams, (1) Bragg Cell or Acousto-optic modulators, (2) Rotating diffraction grating. The Bragg cell or the acoustic-optic modulator needs a high frequency RF generator to generate the frequency shifting of the laser beams. Typically a Bragg cell generates frequency shifts higher than 40 MHz. The rotating diffraction grating generates frequency shifts much lower than the Bragg cells, as the grating rotates on a motor shaft therefore the frequency shift is proportional to the speed of the motor. The Bragg cell requires a high frequency RF generator to function, thereby requiring high power. Instead of a Bragg cell, a rotating diffraction grating driven by a micro-motor; it has low power requirement and is much smaller size. To incorporate these features, a MiniLDV from Measurement Science Enterprise Inc, was used.

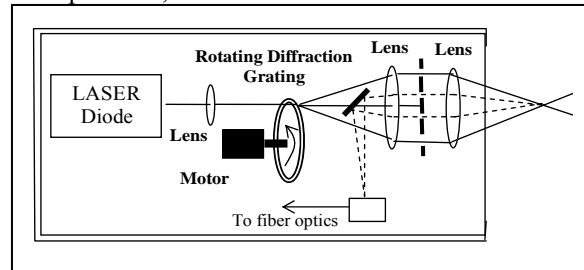


Figure 1: Schematic of the MiniLDV probe

The MiniLDV probe is composed of a laser diode, rotating diffraction grating, transmitting and receiving optics. Its compact size and weight (0.5 lbs) met our requirements in the development of a particle analyzer for Mars. A schematic of the MiniLDV is shown in Fig. 1. The motor speed of the MiniLDV is set to provide a frequency shift between the two beams of 300 KHz. The probe also includes the receiving optics, which is useful for analyzing the particles in back-scattered mode. The two frequency shifted laser beams intersect at approximately 50 mm from the MiniLDV probe, and the intersection creates a fringe pattern with fringe spacing of 1.65 μm .

With the MiniLDV, a relaxation chamber was constructed for detecting Doppler signal bursts. The relaxation chamber incorporates both acoustic and electric drives, so as to measure both charged and uncharged particles. The relaxation chamber is the sensing probe of the DPA. The relaxation chamber is designed to allow the particles to flow through the intersection of the two laser beams generated by the MiniLDV. The acoustic and the electric drives were integrated for individual or simultaneous excitation. The chamber is constructed to allow both back scatter-

ing and forward scattering detection of the particle oscillations.

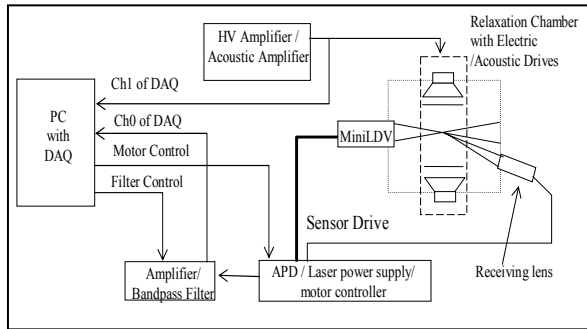


Figure 2: Schematic drawing showing the basic setup of the Dust Particle Analyzer (DPA).

Figure 2 shows the components needed for particle analysis using the MiniLDV and the relaxation chamber. The receiving lens collects scattered light from particles that generate the Doppler signal, which is converted into an FM signal burst by the Avalanche Photo Detector (APD). The signal is filtered using a bandpass filter and is analyzed by the data acquisition card on the PC. The Doppler bursts and the excitation signals are acquired by the data acquisition card. To calculate the particle size and charge from the acquired signals LabVIEW is used, incorporating the signal processing technique of quadrature demodulation for demodulating the FM Doppler burst signal which was developed by DiVito [8].

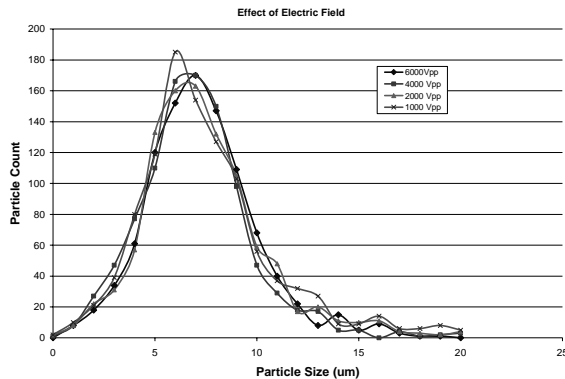
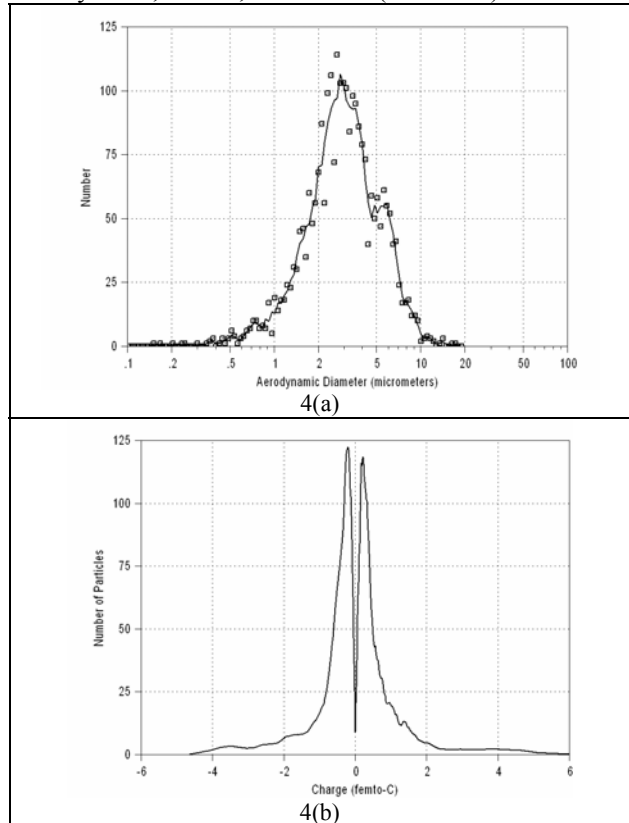


Figure 3: Particle Size distribution with change in Electric field

Results and Discussion: The effect of electric field on the measurement of particle size was analyzed, since the breakdown voltage on the surface of Mars is much lower than that of earth. The DPA was tested to measure whether it would give reliable data with variation in electric field. For testing, toner was tribocharged with stainless steel beads and dispersed using a blow-off cup. The electric field was varied with readings taken at 3000, 2000, 1000, 500 V with a 2.5 cm spacing between the electrodes. About 1000 particles were counted for each run. Figure 3 show that with variation in the electric field, there are no large scale

changes in the particle size distribution.

Mars Dust Simulant: Ideally, the testing of the DPA is to be performed with real Martian dust, since no returned dust samples are available, simulants were used. The Mars Dust Simulant JSC Mars-1 is a natural material obtained from volcanic ash which approximates the various physical and chemical properties of the oxidized soil of Mars [9]. The chemical composition of JSC-1 Mars dust simulant contains predominantly SiO₂, Al₂O₃, and Fe₂O₃ (>82 wt%).



To analyze the PSD and (Q/M)D distributions of the Mars simulant dust, experiments were carried out by generating a dust cloud within a chamber from where the DPA can draw samples of dust particles for measuring the size and charge distributions. Tribocharging of the Mars simulant dust shows how the dust gets charged with various materials such as stainless steel, Teflon, and glass. By tribocharging experiments, one can understand the nature of dust depositing or coming in contact with man made materials.

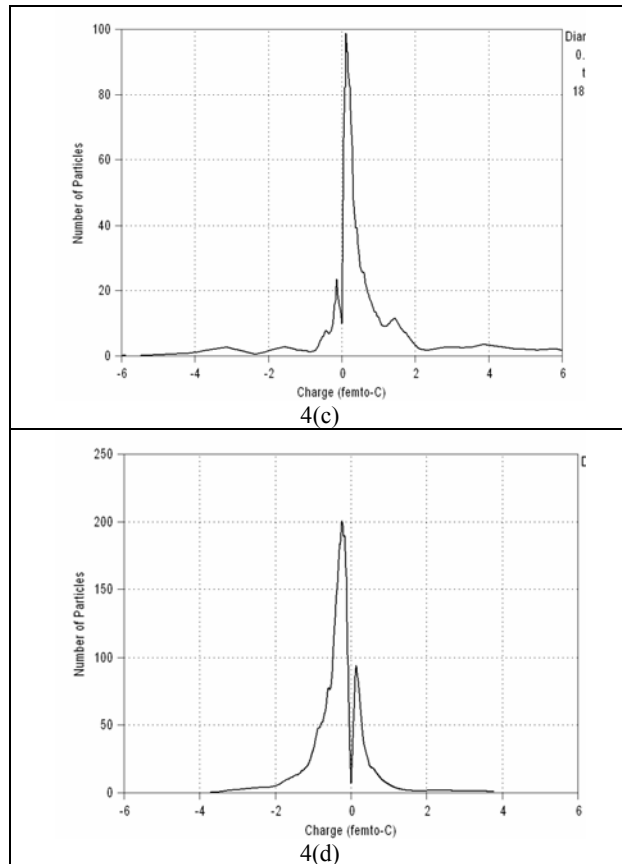


Fig. 4. Characteristics of Mars Simulant Dust JSC Mars-1 showing Particle Size Distribution (a), Charge distribution of dust (b), dust tribocharged against Teflon (c), and against stainless steel (d).

Figure 4 shows the particle size distribution of size classified Mars simulant dust as measured by the DPA analyzer. The aerodynamic median diameter was approximately $3.0\mu\text{m}$. Mars dust when tribocharged against different materials will become more negatively or positively charged based on the work function difference between respective materials.

Testing the DPA under Martian conditions: The DPA was tested in Martian conditions at Kennedy Space Center using the test setup designed by Mantovani et al. [10]. The relaxation cell was placed inside the low pressure test chamber. The chamber was depressurized to 5-7 mb with CO_2 gas mixture. In normal atmosphere, the DPA is operated under 3000V, and 2 KHz excitation frequency, but the voltage has to be reduced under Martian conditions to prevent electrical breakdown. The experiments were done at 900V, and 2 KHz frequency. Figure 5 shows the particle size distribution for classified Mars simulant dust.

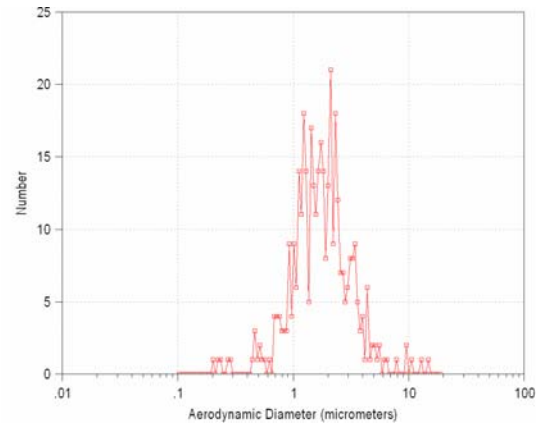


Figure 5. Particle Size distribution of Mars simulant dust under Mars atmospheric conditions.

Conclusion: The Dust Particle Analyzer has been shown to measure both particle size and charge distributions of JSC-1 Mars dust simulant. Particle size and charge distribution measurements of Mars simulant dust were performed under Mar-tian atmospheric conditions. The performance of the instrument shows that real-time and in-situ measurements can be performed on Mars using a modi-fied ESPART analyzer.

Acknowledgement: The work is supported in part by NASA Project No. NRA 02-OSS-01 (ROSS-2002) and by NSF grant award No. 0526977.

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