2003 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

Development of Charge to Mass Ratio Microdetector
For
Future Mars Mission

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ABSTRACT

The Mars environment comprises a dry, cold and low air pressure atmosphere with low gravity (0.38g) and high resistivity soil. The global dust storms that cover a large portion of Mars are observed often from Earth. This environment provides an ideal condition for triboelectric charging. The extremely dry conditions on the Martian surface have raised concerns that electrostatic charge buildup will not be dissipated easily. If triboelectrically generated charge cannot be dissipated or avoided, then dust will accumulate on charged surfaces and electrostatic discharge may cause hazards for future exploration missions. The low surface temperature on Mars helps to prolong the charge decay on the dust particles and soil. To better understanding the physics of Martian charged dust particles is essential to future Mars missions. We research and design two sensors, velocity/charge sensor and PZT momentum sensors, to measure the velocity distribution, charge distribution and mass distribution of Martian charged dust particles. These sensors are fabricated at NASA Kenney Space Center, Electrostatic and Surface Physics Laboratory. The sensors are calibrated. The momentum sensor is capable to measure 45 μm size particles. The designed detector is very simple, robust, without moving parts, and does not require a high voltage power supply. Two sensors are combined to form the Dust Microdetector - CHAL.

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1. INTRODUCTION

To date, there have been no direct measurements on the surface of Mars that characterize the concentration or distribution of the aerodynamic size, mass, shape, or charge deposited on suspended dust [1]. The dust is of great importance on Mars. Dust appears to have both long-term effects on the surface geologic evolution as well as on the aeolian processes in the present climate conditions. Early spacecraft missions confirmed that changes observed in the planet's surface markings are caused by wind-driven redistribution of dust [2][3][4]. Suspended dust is known to alter the atmospheric thermal structure and circulation. Large, planet-encircling dust storms occur on average once every three Martian years [5][6].

There are three sources by which the dust particles can be charged: (1) Saltation, the process by which small grains of dust are lifted off the surface due to impact of a dust-laden flow; (2) Photoionization, [7][8] soil and dust particles acquire a charge due to incident UV radiation; (3) Triboelectrification. The high frequency of dust devil activity in some regions and seasons and the presence of local and global dust storms produce a favorable environment for inter-particle contact charging. This charging is exacerbated by the low humidity in the dry Martian atmosphere. The wind mixes the dry dust and could produce bipolarly charged dust clouds as happens for both terrestrial dust devils [9][10]. Since grain electrification is easier to obtain in the low-pressure dry atmosphere of Mars [11], there is a good possibility that dust raised during storms would undergo intense electrification. Experimental studies conducted at KSC show that simulant dust is highly resistive and has a long charge decay constant at very low temperature.

The primary objective of this project is to develop the Dust Particle Analyzer (DPA), a microdetector that is capable of performing real time, simultaneous measurements of the mass, the velocity and the electrostatic charge distributions of dust particles in the Martian aeolian process. This objective will be achieved by: (a) the design and development of a low cost, simple, and robust detector; (b) calibrating, breadboard testing and design concept improving; (c) testing and evaluation of the detector in simulated Martian atmospheric conditions with respect to temperature and pressure for the measurement of mass, electrostatic charge, and velocity distributions. This detector is named - CHAL.

2. CHAL DETECTOR DESIGN

. The CHAL detector consists of two major components. They are: (1) velocity/charge sensor; (2) mass/momentum sensor. These two sensors, each serving different purposes, combined to form the detector as shown in Figure 1. The velocity/charge sensor measures the charge of particle and TOF (time of flight) as the particle passed through two identical capacitors at a pre-determined distance.
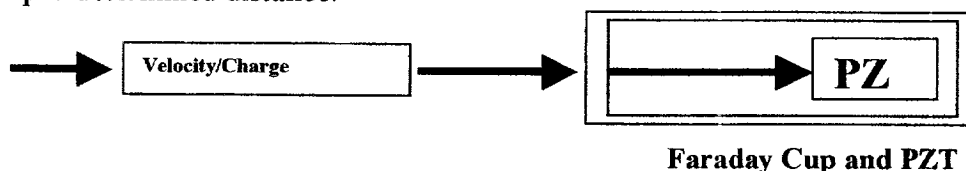

Faraday Cup and PZT

Figure 1. Charged dust particles pass through velocity/charge sensor impacts on the momentum-PZT sensor.

The mass/momentum sensor utilizes a piezoelectric ceramic (PZT) to measure the impact momentum delivered to the PZT. Obtaining the velocity from the first sensor, we can calculate the particle's mass.

2.1 Momentum Sensor

Momentum sensor uses the property of Piezoelectric Transducer (PZT) that changes the mechanical energy (crystal distortion due to stress applied -- impacted particle's momentum) into electrical voltage. By calibrating the momentum/voltage relationship the voltage output is translated into the impact momentum of the incident particle as depicted in Figure 2.
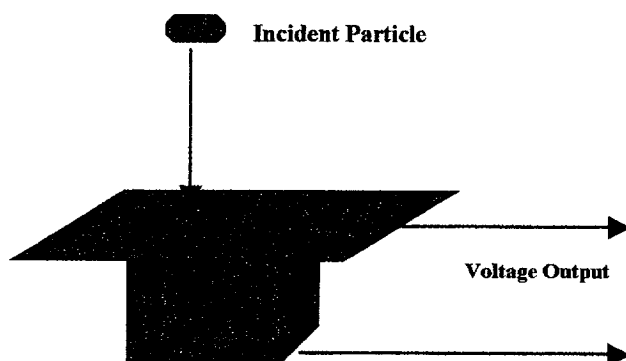

Figure 2. The top plate of PZT Transducer received the momentum from incident particle causes a voltage change at the output

The PZT sensor is calibrated by using "bead dropping" procedure. Different spherical masses (beads) are dropped from different heights to induce a voltage at the PZT output leads. We use 1.4 mg, 2.0 mg and 7 mg iron beads and drop these beads from .1 cm to 3 cm. The results are presented in figure 3. The equation from the curve fitting shows a 0.4377 power factor, which is very close to the 0.5 factor calculated value. Figure 3 presents the relationship between impact momentum and PZT voltage response.

$$y = 146.72x^{0.4377}$$
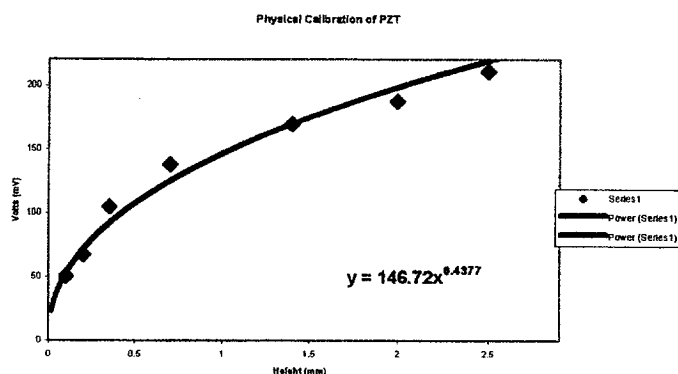
Figure 3. Beads Dropping Results for 2mg iron sphere.

PZT Calibration Normalization
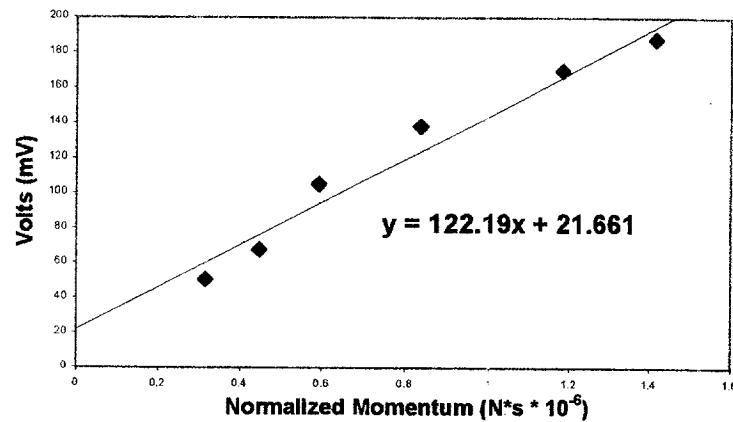
Figure 4. Normalized PZT Bead Dropping of 2 mg iron sphere at different Height. The minimum voltage at x = 0 is 21.661 mV.

The PZT used has a noise level of 10 mV. Including the minimum voltage 21.661 mV from PZT gives the low threshold of 30 mV as shown in Figure 4. The 30 mV is at $0.68 * 10^{-6}$ Ns, the lowest impact momentum that is detectable by our disc PZT. For a particle with 2.4 m/s. the smallest size that can be detected is 45 μm at a density of 2 g/cm^3 (JSC-Mars-1 simulant).

Advantages of the piezoelectric sensor, PZT, are: (1) low cost of producing and processing; there are many different type sensors for a wide range applications readily available commercially; (2) can be form a different shapes and sizes so it is very adaptive to the instrumentation need; (3) momentum-to-voltage sensitivity can be very high. In this project, we selected a thin disc form PZT. A stack form PZT, instead of disc form, can be selected for higher momentum-to-voltage response to measure smaller particles. The drawbacks of PZT are: (1) temperature dependence - at Mars temperature condition, a temperature calibration parameter will be needed to measure accurately the momentum from the PZT voltage output: (2) PZT is pyroelectric, which means that it is sensitive to sudden temperature. The pyroelectric signal can not be distinguished from the piezoelectric signal. A special caution has to be taken to decide the unwanted signals.

2.2 Velocity/Charge Sensor

When a charged particle passes through the center of a cylindrical capacitor, an equal amount of opposite charge will be induced on the capacitor. By measuring the induced voltage on this capacitor and knowing the capacitance of the cylinder, we can compute the original charge of the passing particle. Setting two cylindrical capacitors at a predetermined distance and measuring the time (TOF) that takes the charged particle to pass through, the particle speed can be calculated. Figure 5 shows a two cylindrical capacitors system that was constructed to perform the experiments. The cylinder is a brass tubing of 0.1875 cm OD, 0.1595 cm ID and 1.0 cm in length. Each cylinder is supported by a 0.5 cm long Teflon spacer and housed inside a 0.347 cm ID brass tube. Two cylindrical capacitors are mounted inside a 0.96 cm ID grounded metal cylinder. The cylinders and amplifiers form the center component of the velocity/charge sensor. Two cylinders are separated by 2.0 cm in the housing tube. The effective separation distance "d" is 3.0 cm. In front of the first cylindrical capacitor, there are three collimator

disks to filter and align the dust particles. The collimator has a small hole, diameter 0.033 cm, at the center of the disk. The charged dust particles must pass through three collimator plates to reach the capacitor sensors.
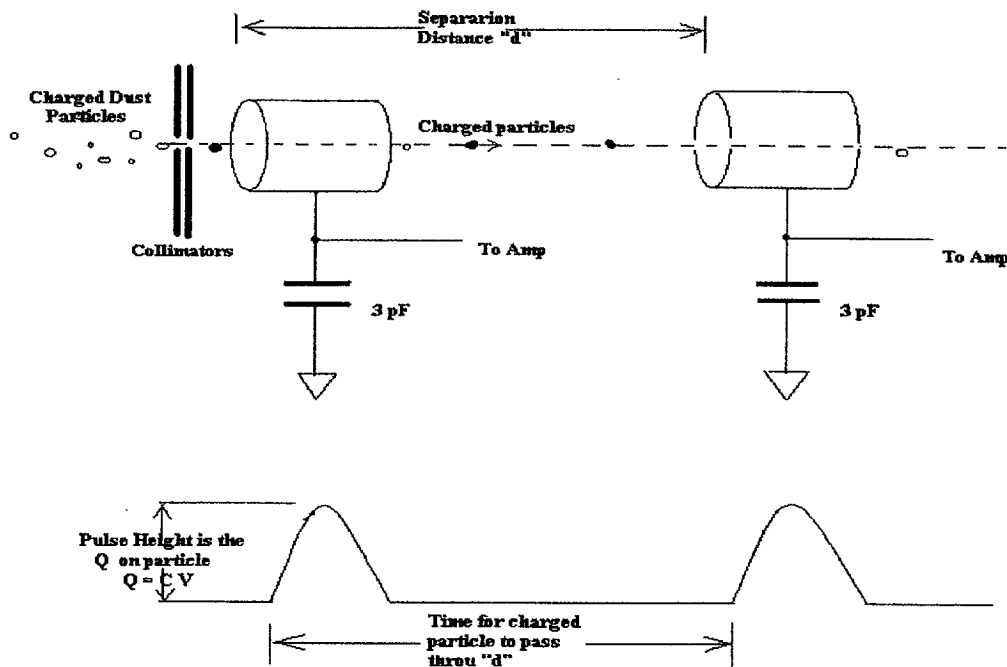
Figure 5. Velocity Sensor Design

The capacitance of the sensing tubing is 49.2 pF [12]. This capacitor in series with a fixed external capacitor, 3.3 pF, forms a voltage divider. The induced voltage is measured through an amplifier with a gain of 21. Figure 6 shows the basic electronics of the amplifier. The amplifier is using a LMC6042 chip, which has two identical OP-Amps. This is a non-inverting amplifier. The total gain of the amplifier is determined by the ratio of two external resisters R_1, R_2, and the voltage divider.
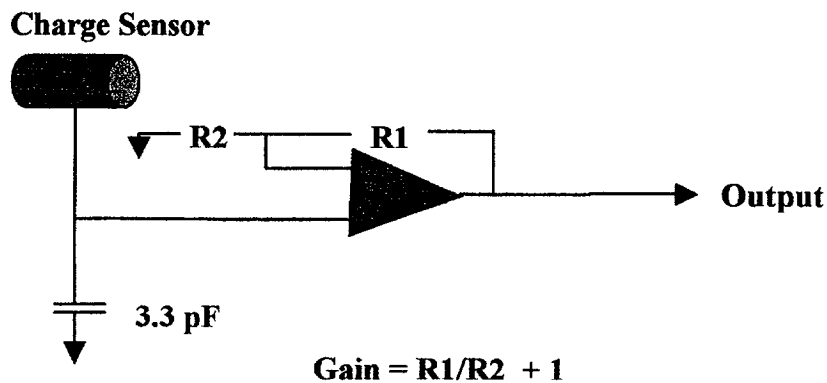
Figure 6. Velocity Sensor Amplifier Circuit

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The amplifier circuitry is derived from the MECA electrometer, a proven flight instrument designed and developed by NASA KSC Electrostatic and Surface Physics Laboratory Team and NASA JPL scientists [13][14][15]. We use this circuit to simplify the design and to cut down the hardware cost. A Tektronix Digital Phosphor Oscilloscope (DPO) model DPO3052 (500MHz, 5GS/sec, 2 channels) was used to collect the data. A DPO probe type P6139A (10 Mohm, 8 pF, 500 MHz, 10:1) was used to pick up the output voltage coming from the sensor amplifiers.

The circuit gain is calibrated by sending a calibrated AC signal through a known external capacitor, 160 pF, which replaces the cylindrical capacitor. The output is measured and compared with the input signal. Figure 7 illustrates the calibration procedures.
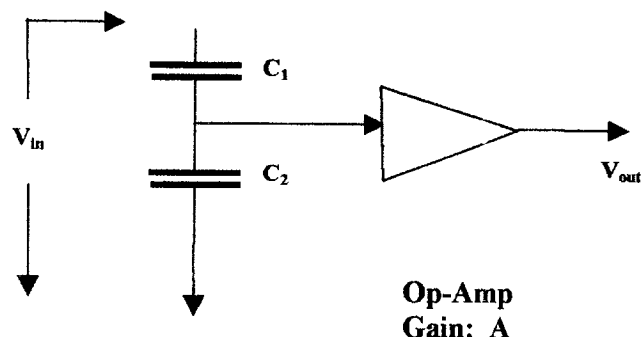

Figure 7. Velocity/Charge Sensor Calibration

The total gain of the sensor G is related to circuit components as

$$ G = \frac{V_{out}}{V_{in}} = A \cdot \frac{C_1}{C_1 + C_2} \cdot V_{in} \cdot $$

The calibrated G is then used to obtain the charge on the cylinder capacitor by

$$ Q_{cyl} = C_{cyl} \cdot V_{cyl} = \frac{V_{out}}{G} \cdot \frac{C_2}{C_{cyl} + C_2} \cdot C_{cyl} \cdot $$

The G value has to be determined by experiment. A signal generator supplies a 200 mV input voltage with variable frequency was used. The data are recorded for V_{out}/V_{in} with respect to frequency.
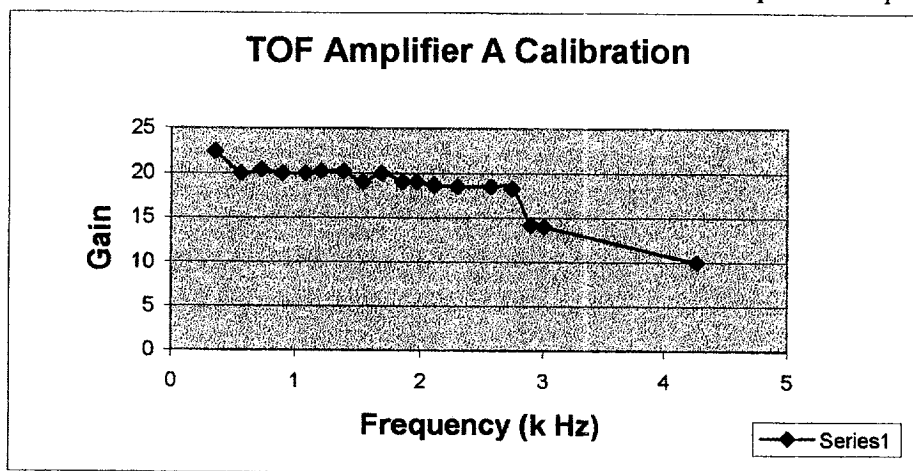

Figure 8. Calibration Results for Amplifier A, the amplifier applies to the first cylindrical sensor. It has a constant total gain between 450 Hz to 2.8 KHz.

Figure 8 shows the calibration results for the first of two cylindrical velocity/charge sensor. The total gain has a fairly flat area at 450 Hz to 2.8 KHz. This means that the amplification within this region is frequency independent. The lower limit of particle speed detectable is around 2 m/s; the upper end is at 12.4 m/s for this constant amplification region. For higher particle speed, the gain factor in the calibration curve has to be taken into consideration.

Delivering dust to the CHAL microdetector testing is the most difficult task. One of the methods is using the Dust Impeller in a vacuum chamber to test the system. The impeller fan propels dust particles to the velocity sensor. We are currently working on different dust delivering schemes.

3. DISCUSSION

The velocity/charge sensor is very simple, inexpensive to build, and can be fabricated into a very small instrument to measure the velocity vector as well as charge of dust particles on Mars. The small cylindrical capacitor configuration with the amplifier has high input impedance. It is necessary to take extra care for noise reduction. We find that by packaging the sensors in a conducting enclosure reduces the noise a great deal. A single dust particle source is needed to test the velocity/charge sensor.

In Martian atmosphere conditions, due to a 0.38 g Martian gravity, the lower limit of particle speed is approximately 1.5 m/s to 2.0 m/s. Slower particle detection can be achieved by shorting the distance between the cylindrical capacitors, and/or increasing the diameter of the cylinders. The upper limit of the particle velocity is controlled by the speed of the electronics.

The Quartz Crystal Microbalance (QCM) has been widely used for micro-scale mass detection. The QCM is reliable and able to detect very small mass. However the electrostatic adhesions of dust particles require an extra effort to clean the detector. The PZT can be made very small. It has a fast response, simple design, and is very inexpensive. The PZT needs calibration for temperature and momentum/voltage sensitivity. We selected the PZT over the QCM for the reasons that PZT handles the dust adhesion with better single response for single dust particle, and smaller physical size. The PZT sensor is capable of measuring the individual particle mass to collect the mass distribution of Martian dust particles and total charges over a given period of time.

4. CONCLUSIONS AND FUTURE WORK

We designed the velocity/charge sensor with a few targets in mind: (1) simple, (2) inexpensive to build, (3) small size, and (4) fewer problems of dust cleaning and maintenance. The current research efforts at NASA KSC Electrostatic and Surface Physics Laboratory are also concentrating on the development of miniaturize the Electronic Single Particle Aerodynamic Relaxation Time (E-SPART) analyzer that is capable of performing real time, simultaneous measurements of the aerodynamic diameter and the electrostatic charge distributions of dust particles in the Martian aeolian process. The E-SPART analyzer requires a high voltage power supply and offers a fast response for possible multi-particles analysis. The E-SPART is quite expensive. The detector developed in this project is a complementary instrument to the NASA KSC E-SPART analyzer to cover the area that requires a quick measurement and works under a more restrained environment. We are also developing the CHAL automation to make this sensor more adaptable to those applications require charge measurement over small particles.

ACKNOWLEDGMENTS

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