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INSTRUMENTATION AND METHODOLOGY DEVELOPMENT FOR 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 were observed often from Earth. This environment provides an idea 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 understand 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 detect the velocity distribution, charge distribution and mass distribution of Martian charged dust particles. These sensors are fabricated at NASA Kenney Space Center, Electromagnetic Physics Testbed. The sensors will be tested and calibrated for simulated Mars atmosphere condition with JSC MARS-1 Martian Regolith simulant in this NASA laboratory.

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1. INTRODUCTION

Mars has a very high resistivity soil and an extremely dry atmosphere. The water concentration in the atmosphere is in the range of 210 PPM [1],[2]. Martian air density is close to 0.02 kg/m^3 and an average dust concentration of 1 mg/m^3 suspended in the Martian air equivalent to 13.4 times the amount of dust in normal air in manufacturing plants on Earth [3]. The local dust cyclone and global dust storm on Mars has a dust loading of 30 mg/m^3, which is 402 times of dust in normal air in manufacturing plants on Earth. The Martian dust storm has these properties; (1) Martian Dust Storms can occur at any time of the year, (2) Typical storms cover areas of one million square kilometers, (3) Storms contain particles having speeds of 25-65 m/s. This environment provides an idea condition for triboelectric charging. [4],[5]. The extremely arid 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 [6].

Martian dust plays a major role in all of the surface interactions considered. Space systems affected by Martian dust and electrostatic charging on Mars are (1) solar cells and viewing ports, (2) thermal radiators, (3) moving parts on vehicles and machines, (4) space suits and life support systems, (5) communication systems, and (6) fuel production and storage systems.

Kolecki et al. at NASA Glenn Research Center reported that 350 volts was observed in their WAE experiment [7]. It is also believed that an article moving on Mars may charge more strongly than the wheel did in the laboratory. Pathfinder wheel charging was observed nearly independent of the rotation speed and wheel slip. It is suggested that charge generation may have resulted from triboelectric effects in the dust when compacted by the wheel.

The dust particles behave as a dielectric medium in Martian atmosphere. These charged dielectric particles accumulate space charges and generate a reverse electric field, which terminates the corona discharge. It is possible to produce highly active plasma without sparking [8]. The plasma generated has a high electron temperature and low gas temperature that is able to enhance chemical reactions. This partial (silent) discharge behavior is also possibly helping insulation [9] and increasing the total charges on the soil surface.

When strong surface winds and a resulting large dust mass loading in the course of large dust storms occurring on Mars, there is possible to produce large electrical discharge - lightning on Mars [10].

To characterize the dust charge and speed in the Martian atmosphere, two sensors are designed to perform these tasks. The design and tests of new sensors are described and presented in the following sections. We conclude with a discussion of the results of the experiments, and present conclusions about the new sensors.

2. Sensors Design

The design and development two sensors, (1) charge and velocity sensor, and (2) mass/momentum sensor, are presented in this section.

2.1 Velocity/Charge Sensor

The purpose of this sensor is to measure the amount of electric charge and airborne dust particle velocity. It is based on the fact that 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 this cylinder, we can compute the original charge on the passing particle. Setting two cylindrical capacitors at a pre-determined distance and measuring the time that takes the charged particle to pass through, the particle speed can be calculated. Figure 1 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 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 ID brass tube. This outside tube serves as an integrated housing and insulator to shield the external noises. 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.

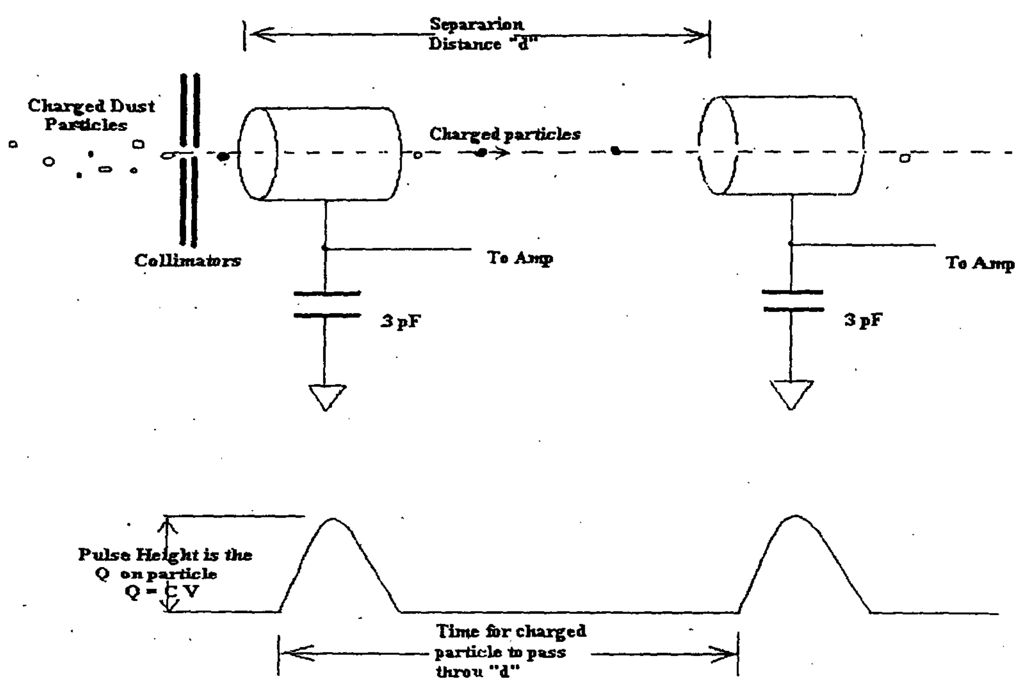


Figure 1. Velocity Sensor Design

The capacitance of the sensing tubing is 4.5 pF. This capacitor in series with a fixed external capacitor, 3.0 pF, forms a voltage divider. The induced voltage is measured through an amplifier with a 50 times gain. Figure 2 shows the basic electronics of the amplifier. The amplifier is using a LMC6044 chip, which has four identical OP-Amps. Two OP-Amps are used to form a complete amplifier for each cylindrical sensor. The total gain of the amplifier is determined by the ratio of two external resisters R_1, R_2, and the voltage divider.

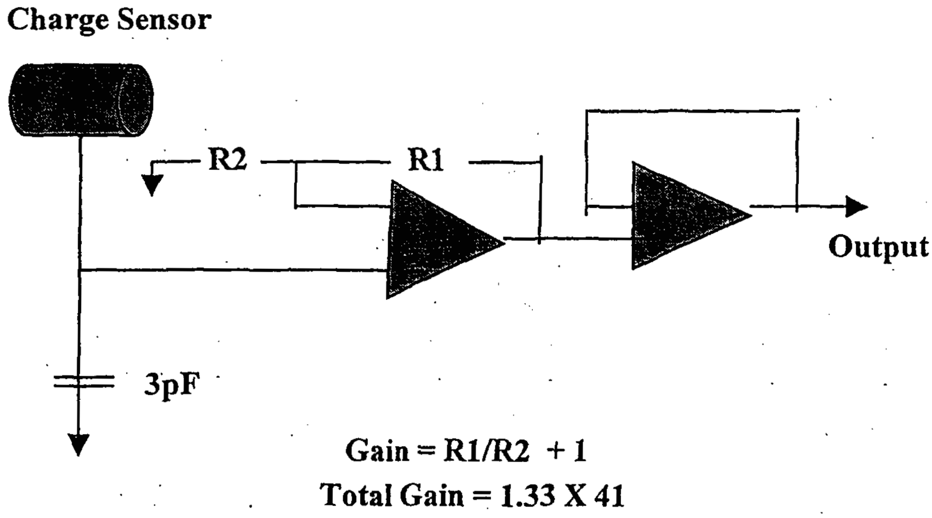


Figure 2. Velocity Sensor Amplifier Circuit

The amplifier circuitry is derived from MECA electrometer, a proven flight instrument designed and developed by NASA KSC Electromagnetic Physics Testbed Team and NASA JPL scientists [11],[12],[13]. 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 in the vacuum chamber.

Martian dust storms will be simulated in a vacuum chamber using an impeller fan to propel dust particles to the velocity sensor. When the impeller fan is turned on the dust particles moving in the chamber will be charged triboelectrically. The Martian soil simulant is propelled towards the velocity/charge sensor. The charged dust particles passed through collimators will enter the cylindrical capacitor sensors as shown in figure 3.

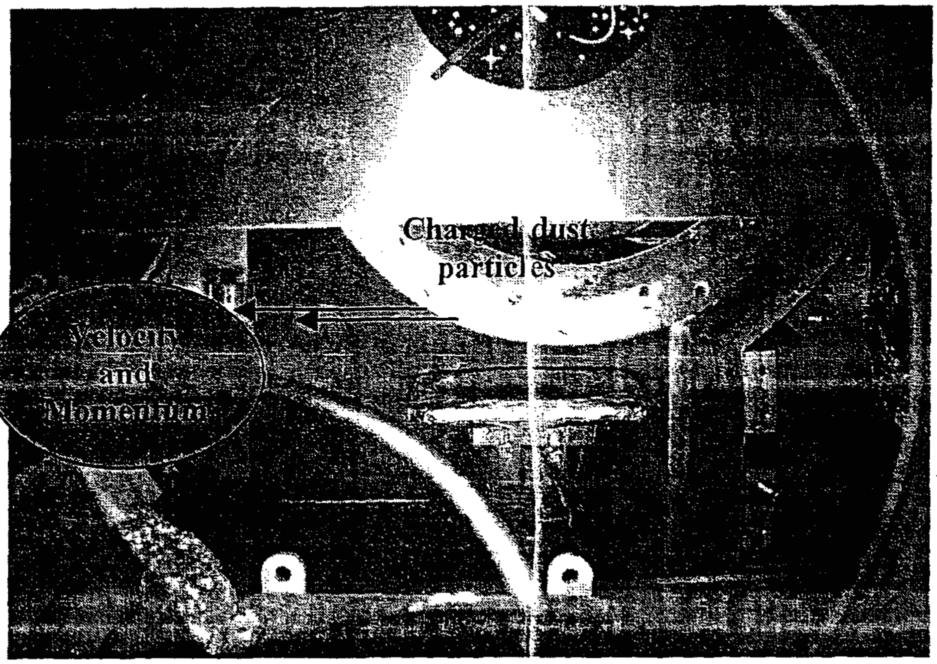


Figure 3. The velocity/charge sensor and dust impeller apparatus shown in the small vacuum chamber where experiments will be performed.

The windborne dust particles would pass through the sensor detecting cylinders. Data will be taken with the velocity sensor under conditions that attempt to simulate a Martian dust storm.

2.1 Momentum Sensor

Momentum sensor is utilizing the property of Piezoelectric Transducer (PZT) that changes the mechanical energy (crystal distortion due to stress applied) into electrical voltage. Figure 4 shows an incident particle with a momentum **P**. The particle impacted on the top plate of PZT produces a voltage output. By calibrating the momentum/voltage output, the voltage is translated into the impact momentum of the incident particle.

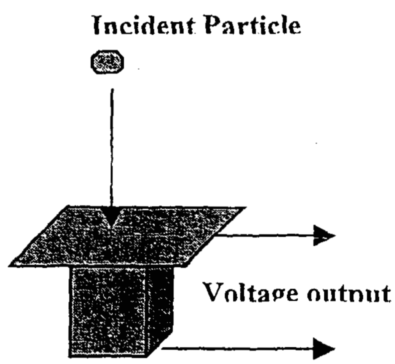
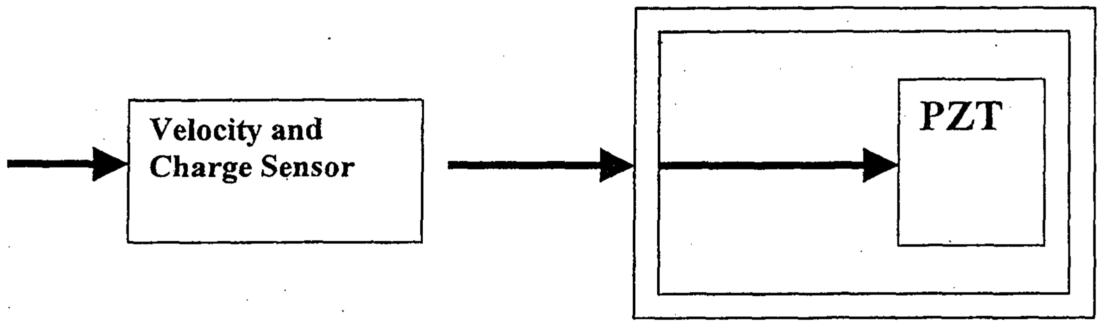


Figure 4. PZT Transducer



Faraday Cup for total Charge measurement

Figure 5. Charged dust particles pass through velocity/charge sensor will be collected by a Faraday Cup for total charge counts. The momentum of each particles is measured by a PZT sensor.

Knowing the momentum, **P = mV**, we can calculate the mass of the incident particle. The PZT momentum sensor and the velocity/charge sensor are integrated into one unit for the dust particle mass, charge and velocity measurement.

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 and charging of charged 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. A single dust particle source is needed to calibrate the velocity/charge sensor.

In the Earth atmosphere environment, the lower velocity limit for this design is around 4 to 5 m/s. Slower particles detection can be achieved by shortening the distance between the cylindrical capacitors, and/or increase the diameter of the cylinders. In the Martian atmosphere condition, due to a 0.38 g of Mars gravity, the lower limit of particle speed is approximately 1.5 m/s to 2.0 m/s. The upper limit of the particle velocity is controlled by the speed of electronics. The current design is capable to measure charged particle speed up to a few km/s. This sensor is designed to collect the information of speed distribution and charge distribution of Martian charged dust particles.

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 adhesion of dust particles require an extra efforts to clean the detector. The PZT can be made very small. It has a fast response, simple design and very inexpensive. The PZT needs to calibrate for temperature and momentum/voltage sensitivity. We selected the PZT over 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 WORKS

We designed the velocity/charge sensor with a few targets in mind (1) simple, (2) inexpensive to build, (3) the size can be very small, and (4) less problem of dust cleaning. Two velocity/charge sensors have been fabricated for our laboratory analysis. The current tasks to improve these sensors are (1) electronic noise reduction, (2) miniaturize the sensor, and (3) improve collimation for single particle detection. A Grid Correction circuit to improve the single particle selection can be used. We are also doing research to select the best PZT to improve temperature drifting and momentum/voltage sensitivity.

We are planning to combine the velocity/charge sensor and the PZT sensor to form an integrated unit. The small size and expense of these two sensor type makes this unit easily form a detector array for better Martian dust characteristic study.

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