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Cosmic Dust Detection with Large Surface Piezoceramics

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ABSTRACT

I. Introduction

Piezoelectric transducers mounted on targets made out of metal plates or plastic foils have been used in many former space missions to detect impacting dustparticles and to determine some of their parameters (e.g. momentum). The proposed detector is based on a large disc made out only of piezoceramic material.

II. Basic Principle

Dustparticles impacting on the detector will cause electrical charge pulses due to the piezoelectric nature of the targetmaterial (Fig. 1). These charge pulses are measured on the electrodes of the disc and transformed with a charge sensitive amplifier (CSA) to voltage pulses. Counting the number of pulses leads to the dustflux impacting on the detector. Additionally the amplitude and the risetime of the pulse slopes are determinated to evaluate the momentum and the size of the dustparticles. Due to the high charge production rate per force unit of piezoceramics and a momentum transfer without loss the sensivity of this acoustic sensor is very high.
To derive size and momentum from the rising slope of an acoustic signal is a new method and will be described shortly in the following paragraph.

III. Theory

The dimensions of the target are assumed much larger than the particle ones. When a small mass is impacting on a target with high velocities (Fig. 2a) compressional shockwaves are travelling from the contacting area both into the target and the particle (Fig. 2b). The shock waves travelling through the particle are reflected inversely at the free end of the rear of the particle and travel back again through the particle. On the other hand the shock waves inside the target are travelling unchanged deeper into the target increasing the internal pressure; this represents the partly transfer of momentum from the particle to the target (Fig. 2c). Due to the interferences of the shock waves the particle and the contacting zone of the target are heated up very strongly and material is vaporized. Nevertheless its deceleration the particle has still a velocity along the former flight direction. Although the particle and the contacting area begin to explode into a debris cloud the shock waves in the particle will be reflected again into the exploding particle and will travel through and back again. So the piezoceramic target is pressed continuously under the impacted area and the pressure waves are travelling from the contacting zone deeper into the target. Due to the piezoelectric effect a piezoelectrical material which is polarized in the direction of impact will respond to the impact with a monotonic increasing charge displacement which can be measured at the electrodes (Fig. 2b-f, right part). When the momentum transfer from the particle to the target is finished the internal forces and therefore the generated charge begin to decrease (Fig. 2c-f), because the velocity vector of the loading debris cloud is versed by 180°. If the first front of shock waves has not reached yet a free end of the target the amplitude of the charge signal at this time is the sum of all "shock packages" which are transferred from the particle to the target; it is correlated to the force which is caused by the now totally transferred momentum of the particle prior to the impact. This condition can be fulfilled with the target design so that the travelling time of the compressional shock waves in the target in and cross the travel direction is longer than the momentum transfer times for the considered particle sizes. Because the momentum transfer time is a function of travelling time of shock waves through the particle, the risetime of the slope of the charge signal depends on the size of the particle.

IV. Sensivity

The resolution of particle size depends on the available time resolution of the rising slope, the time delay due to the electrical capacities, and the momentum transfer time. At the present the available clock frequency is 1 GHz, the time delay can be held < 10 ns, and the momentum transfer times take $\cong 5$ times the time of shock waves travelling through and back the particle. To achieve a considerable accuracy the momentum transfer time should be at least as long as the time delay. Therefore only the size of particles with diameters $\geqq 5$ µm can be determinated directly from the risetime of the charge signals slope. For the counting mode of the detector these restrictions are less important. Therefore the sensivity for counting is much higher than in the size determination mode; it is only limited by the maximum frequency of the electronics: It is possible to count high-velocity-particles with diameters down to 0.5 µm.

The accuracy of determining the particle size varies with the diameter: For particles of diameters $\cong 5$ µm the error accounts to ca. 50 %, for diameters of 10 µm the error is ca. 35 % and so on.

The momentum of the particle can be calculated from the amplitude and the time of the rising slope. At this evaluation the errors of the two components are partly compensated. So the momentum-error accounts only to e.g. 30 % for particles with diameters of 5 µm or 20 % for particles of 10 µm.

V. Options

In Fig. 3 a possible option is depicted where the generated charges of the piezoceramic are not measured by a CSA but directly transformed in a voltage by a resistor. This option has the advantage that no power source is necessary at the experiment, because the detector works as a voltage source. The sensivity in the counting mode is reduced to particles above 4 µm in diameter.

Another option is shown in Fig. 4: A thin plastic foil is stretched in a distance before the detector plate. The foil is electrically conductive at the circumference so that impact generated plasma charges of the foil can be measured as the start puls of a time-of-flight-measurement. The stop puls is derived from the detector signal. So the velocity of the particle can be calculated. The advantages of such a two-stage-detector are both a highly improved accuracy respectively the particle mass and the possibility of determination of the density or the shape or the impact angle of the particles.

VI. Conclusions

The proposed detector principle of exposing a large surface piezoceramic to cosmic dust to determine the dustflux, the momentum and the size of the impacting particles is a newly developed method. Two possible options are discussed to improve the accuracy and the modes of the present experiment. Further studies will be made to improve the determinable sizes to submicron ranges and to combine the basic detector with extensions for multiple applications.

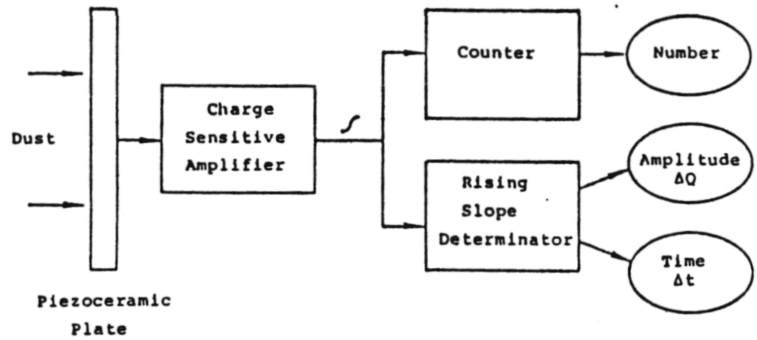

Fig.1
Detector Principle

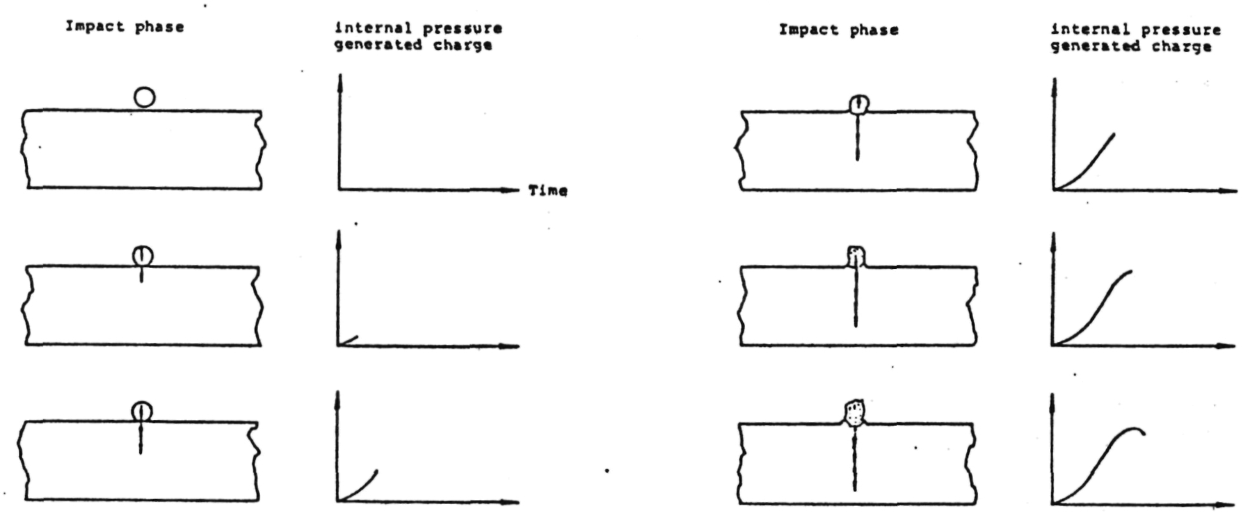

Fig.2
Impact on a Piezotarget

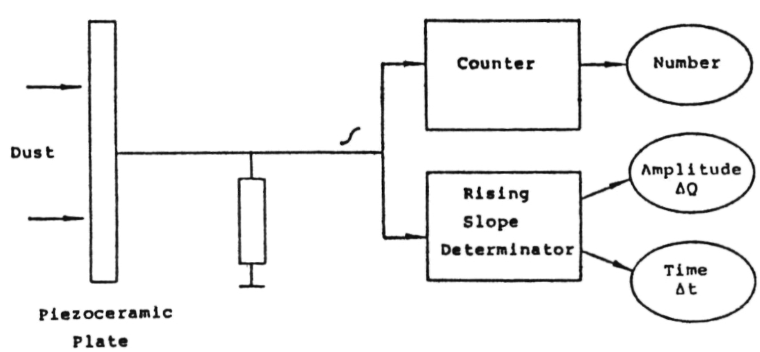

Fig.3
Option 1:Voltage Source

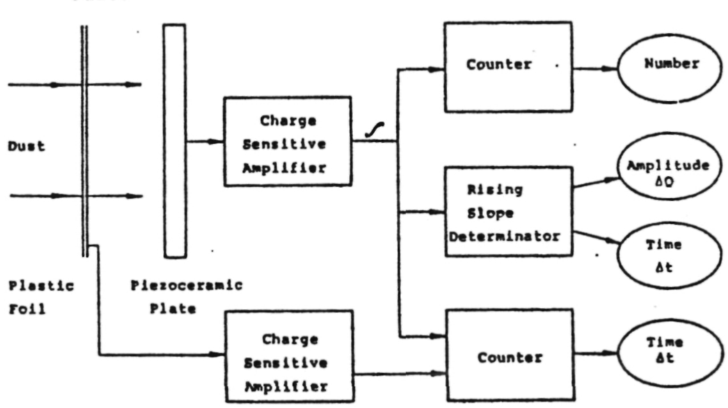

Fig.4
Option 2:Two-Stage-Detector