IN-SITU DETECTION OF METEOROIDS AND ORBITAL DEBRIS

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ABSTRACT

Most of the sensors currently in use for the detection of micrometeoroids and small space debris do not provide independent measurements of mass and velocity. CNES and ONERA have developed technologies for the design of active sensors (MOS or PVDF). These sensors however are able to obtain the value of only one parameter (momentum or kinetic energy) of the detected particle. More data require the use of at least two-stage instruments. The first stage must not change the integrity of the projectile. This is the case for an optical curtain: when a particle crosses it, the scattered light is detected. The interval of time measured between this detection and the impact on the second stage allows computing the velocity of the particulate. We propose a new design for such a detector. We will show that the mass and a rough estimate of the size of the particle and of the direction of the velocity can be obtained.

1. INTRODUCTION

There is a growing need for a better knowledge of the solid particle environment in low earth orbits. This is crucial for the design and the survival of space missions especially when human security is concerned. Indeed, surface damage resulting from the impact of small particles (less then 1 mm), which separately is not lethal for a spacecraft, may become one of the major concern for sensitive devices used in space (optics, thermal control coatings, solar cells) especially for long term mission. Moreover meteoroid streams can produce poorly known damages. In the case of brittle materials, ejecta from both sides of the surface could lead at internal damage and creation of new debris and potential interaction with other areas of the structure and an increase of the total population. During the recent years, several spacecraft missions have flown sensors devoted to the monitoring of this peculiar environment (Berthoud, 1993, Simon et al., 1993). However most of the detectors consisted of passive surfaces, retrieved after their exposure to space. In these conditions, most of the data obtained were limited to low earth orbits. Moreover, a few active experiments did indicate a non-random distribution of particles, in space and in time (Maag, 1996, Simon et al. 1993). In the recent years ONERA and CNES have been involved in the development of active detectors which could be used for the real time monitoring of the small orbital debris. We propose here an improved design, based on available technology. It would be possible to study micron-sized debris whose population and its evolution is not well understood. If detectors are retrieved well documented hypervelocity impacts could be studied.

2. APPROACH

2.1 MOS sensors

Capacitor discharge type sensors, relatively simple devices, have been used extensively on spacecrafts. Their initial low sensivity however limit their use to the detection of relatively large particles. Instead, the MOS detector are based upon the monitoring of the discharge of a parallel-plate capacitor using a very thin dielectric The current MOS sensors use a technology developed earlier by NASA, for the detection of solid particles in the size range from sub-micron to 100 µm diameter (Kassel and Wortmann, 1995). The device is operated with an electrical potential applied across the capacitor plates, hence a charge is normally stored in the capacitor. When a particle impacts the plate with enough energy, it can cause the dielectric to breakdown and result in an internal discharge of the capacitor. The event can be measured by monitoring the current required to recharge the capacitor. Evaporation of the electrode around the impact site usually prevents the occurrence of a permanent short. The sensitivity of the detector depends on several factors such as the dielectric thickness, the top electrode material and thickness, and the applied bias voltage. Within given mass and power constraints (1 kg, 1 W) a standalone instrument has been made. Each module uses 4 silicon wafers mounted on a top aluminium plate; each wafer is divided into 2 sectors. Outside dimensions of the box are currently 120 x 120 x 100 mm (Durin and Mandeville, 1997).

2.2 PVDF sensors

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Sensors using the piezo-electrical properties of PVDF (polyvinidylene fluoride) have been pioneered by Simpson and Tuzzolino (1989). They have been used on the Vega Probe to Halley comet (Simpson et al., 1986). Similar devices have been flown recently on Cassini and Stardust spacecrafts. Material is permanently polarized upon manufacturing. PVDF foils are available in a wide range of thicknesses (> 6 µm) and shapes; mass of sensing device can be very small. When impacted by an hypervelocity particle, a local depolarisation electric signal is produced and monitored. Associated electronic consists mainly in charge sensitive and pulse shaping amplifiers. Laboratory calibrations have shown that the magnitude of the electrical signal is related to the kinetic energy of the particle. Nevertheless, as for as MOS detector, this detector is able to deliver the value of only one parameter of the projectile. More information requires the use of a two-stage instrument. Impact velocity of the incoming particle can be deduced easily from the time of flight (TOF) measurement between the two detectors.
A prototype using a double stage PVDF device (9 µm for the first and 25 µm for the second foil) has been developed at ONERA and CNES, as shown on Figure 1 (Mandeville, 1999). It has been tested under impact with high velocity particles (Igenbergs, 1973, Sitte, 1967). Velocity measurement for particle larger than 50 µm was possible; however this was not the case for small particles as they are destroyed upon impact on the first foil. In particular the velocity of micro-sized debris, whose population is not well known, and of cosmic dust, such as β meteoroids, can not be studied. An alternate, non destructive, method must be used.

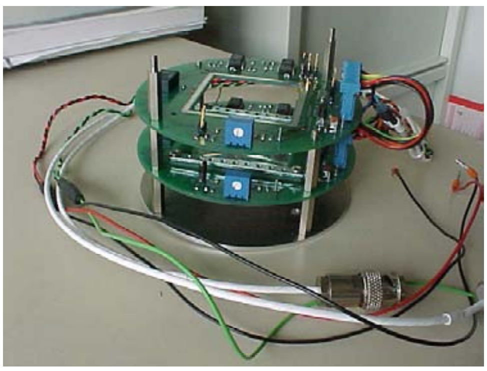

Figure 1. Two-stage PVDF sensor

3. DESIGN OF A NEW INSTRUMENT

3.1 Approach

In order to obtain a measurement of the impact velocity, the first stage of the instrument must preserve the integrity and the dynamics properties of the particulate. It is the case for an optical curtain such as the one used on the GIADA instrument of the ROSETTA space mission (Epifani et al., 2002). When a particulate crosses the curtain, the light it scatters is detected. The interval of time measured between this non disturbing detection and the impact on the second stage allows to compute the velocity of the particulate. This second stage gives its kinetic energy. Then its mass can be computed. Moreover a rough estimate of the size (and consequently of the density) of the solid particle and of the direction of the velocity can be deduced respectively from the intensity of the scattered light and from the crossing position of the screen and the position of the impact on the second stage. In the case of a retrievable instrument, analysis of impacts would allow to be more specific about the properties of the particulate.

3.2 Optical fence first stage

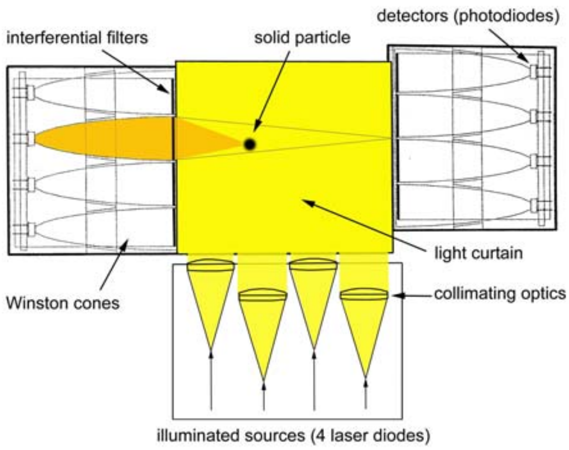

Figure 2 Design of the optical fence

Two designs are proposed. The first one (Fig.2) is similar to the first stage of Grain Detection System included in the GIADA instrument aboard the ROSETTA spacecraft (Epifani, 2000, Epifani, et al., 2002). The incoming particulates pass through a light curtain whose surface is 10cm x 10cm and whose thickness is 0.5cm. In order to obtain a high irradiance on the solid particles, the light is emitted by four laser diodes at the wavelength $\lambda = 915$ nm. Each laser diode has its own collimating optics mainly composed by two lenses, one objective and a rectangular diaphragm to shape each laser beam into a parallelepiped of light.

Inside the curtain the irradiance of a particulate reaches 0.5 W/cm^2. The detection part of this stage is composed of Compound Parabolic Concentrators (also called Winston cones) (Winston, 1970, Winston 1971): they concentrate the light scattered by a solid particle on the small surface of the photo diodes used as detectors at each cone exit. Spurious light is eliminated using an interferential filter set at the entry of each cone. Calculations of the flux scattered by aluminium oxide particles (spherical debris generated as part of normal combustion processes or as by-product of such processes) on a photo diode are presented on Table 1. We have supposed that the crossing of the curtain by the debris are centred, the angle of incidence is 0° and the velocity is $12 km/s$. The transmission coefficient of a detection channel is 0.6.

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Size of the particle (in micron)	Scattered light on a photo diode (in photons)
10	2.1 10^2
100	1.79 10^5

Table 1

This design is not optimum because the mean scattering angle is 90° i.e. the efficiency of the scattering is minimum. A major improvement could be obtained if the detection channels are located just above and/or under the light curtain, in the direction of the incident light. The measured scattered light is collected quite near the forward or the backward direction. Calculations show the improved sensitivity of this design (Table 2 near the forward direction and Table 3 near the backward direction). It will permit the detection of micron sized particulates.

Size of the particle (in micron)	Scattered light on a photo diode (in photons)
10	1.16 10^5
100	5.45 10^6

Table 2

Size of the particle (in micron)	Scattered light on a photo diode (in photons)
10	7.66 10^4
100	3.62 10^6

Table 3

3.3 Second stage

The second stage must be able to provide a measurement of the kinetic energy or of the momentum of the impacting particle. The technologies described earlier can be used : MOS capacitor sensor or PVDF foil, choice is depending mainly upon resources available from the spacecraft.

MOS sensors can be used for the second stage, they have been tested and calibrated. However mass and power constraints would not recommend their use for a two-stage detector. Presently, the use of PVDF material appears to be the best suited for the design of a two-stage detector. The low weight material does not require an external bias supply.

Previous calibrations have shown that the magnitude of the electric signal produced by the impact of a particle on the PVDF depends upon the kinetic energy and upon the area affected by the shock. Simpson and Tuzzolino (1989) have developed a model to compute the charge, Q, produced upon impact. It is related to the built-in volume polarization (dipole moment per unit volume) of magnitude **P** (a typical value of P is 5 μC/cm^2) and to the area, A, of the zone impacted. For a non perforating particle, the charge can be computed as follows:

$$Q = 3.1\ 10^5\ A \text{ electrons (with A in } \mu^2)$$

A fit of the experimental data obtained during tests performed in Heidelberg (MPI) is shown on the Figure 3, for several velocity ranges.

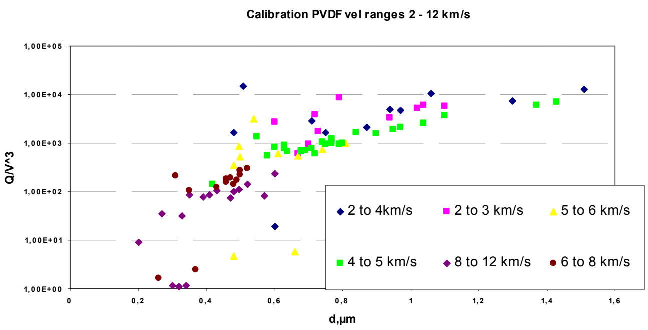

Figure 3. Amplitude of the charge vs. diameter of particle (tests made at MPI Heidelberg)

Detection threshold: upon the tests performed with the electrostatic dust accelerator, iron particles of 1 μm in diameter, with a velocity of 2 km/s, have been detected (0.5 μm at 5 km/s).

3.4 Current design : Optical Fence and PVDF.

In order to measure independently the mass and the velocity of the particles a two-stage detector is proposed. The Figure 4 shows a possible compact configuration. The optical fence is made with 4 light emitting laser diodes and 8 Winston cones fitted with photodiodes, as described earlier. The second stage is made with an array of 16 individual PVDF foils (25 or 40 µm thick). This configuration would allow, at some extent, a determination of the angle of incidence of the particle. A distance of 100 mm between the stages will provide a good accuracy for the time of flight measurement.

Electronic box will be located underneath the PVDF stage.

Size of a self-contained modular unit is presently 300 x 200 x 300 mm, for a sensitive area of 100 x 100 mm. Estimate for the mass and power are the following: 4 kg and 8 W.

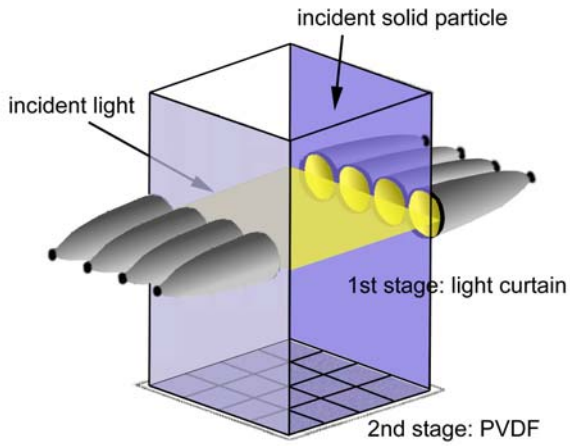

Figure 4. Two-stage mass-velocity detector

4. CONCLUSION

The type of two-stage detector described in this paper can be used to monitor the small particulate in the earth environment. It is best suited to the detection of micron sized particles on a routine basis. The design is based on technology already developed for spaceborne missions (ROSETTA, CASSINI), it will be suited for the measurement of impact velocity of the particles, parameter of importance for the determination of their origin. Its use on satellites in geostationary or polar orbits will increase our knowledge on the distribution and on the evolution of man-made orbital debris and micrometeoroids.

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