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GIADA: extended calibration activity:

the Electrostatic Micromanipulator

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Abstract. GIADA (Grain Impact Analyser and Dust Accumulator), one of the scientific instruments onboard Rosetta/ESA space mission, is devoted to study dynamical properties of dust particles ejected by the short period comet 67P/Churyumov-Gerasimenko. In preparation for the scientific phase of the mission, we are performing laboratory calibration activities on the GIADA Proto Flight Model (PFM), housed in a clean room in our laboratory. Aim of the calibration activity is to characterize the response curve of the GIADA measurement sub-systems. These curves are then correlated with the calibration curves obtained for the GIADA payload onboard the Rosetta S/C. The calibration activity involves two of three sub-systems constituting GIADA: Grain Detection System (GDS) and Impact Sensor (IS). To get reliable calibration curves, a statistically relevant number of grains have to be dropped or shot into the GIADA instrument. Particle composition, structure, size, optical properties and porosity have been selected in order to obtain realistic cometary dust analogues. For each selected type of grain, we estimated that at least one hundred of shots are needed to obtain a calibration curve. In order to manipulate such a large number of particles, we have designed and developed an innovative electrostatic system able to capture, manipulate and shoot particles with sizes in the range 20 - 500 μm. The electrostatic Micromanipulator (EM) is installed on a manual handling system composed by X-Y-Z micrometric slides with a 360° rotational stage along Z, and mounted on a optical bench. In the present work, we display the tests on EM using ten different materials with dimension in the range 50 - 500 μm: the experimental results are in compliance with the requirements.

Key words. GIADA Calibration – Electrostatic Micromanipulator – Comet dust analogues

1. Introduction

The ESA Mission's Rosetta will characterize the cometary nucleus and the coma of the short period comet 67P/Churyumov-Gerasimenko by means of 10 Landers and 12 Orbiters payloads. Among the latters, GIADA (Grain Impact Analyser and Dust Accumulator) will characterize the dust environment and its evolution in the cometary coma.

The GIADA instrument consists of three measurement sub-systems:

1. The GDS (Grain Detection System), an optical device counting the individual grains and measuring their optical cross-section. It detects the transit of each single grain entering GIADA and crossing a laser curtain, with no effects on its dynamical properties (Mazzotta Epifani et al. 2002).

2. The IS (Impact Sensor), a device devoted to the measurement of the momentum of each single grain impacting the sensitive surface constituted by an aluminum plate connected to five piezoelectric sensors. The IS is placed below the GDS, at a distance of 100 *mm*. The coupled detection by GDS+IS provides the speed and mass of individual dust grains. The time of flight of a particle between GDS and IS allows the measurement of the velocity component parallel to the Z axis of GIADA, i.e. perpendicular to the IS aluminum plate. Combining this value with the measured momentum, the mass of each grain is derived.
3. The MBS (Micro Balance System) is constituted by five Quartz Micro Balances (QCM). The five QCMs point towards different space directions and measure the cumulative deposition in time of dust grains smaller than 10 μm (Palomba et al. 2002).

For a detailed GIADA description and related performances see Colangeli et al. (2009).

GIADA PFM, housed into a clean room in our laboratory, is presently used to perform the calibration activity in order to be ready for the Rosetta scientific phase that will start in about one year. The aim of this activity is to create a database for the sub-systems behavior that will be used for the reduction of the data that GIADA will collect during the comet phase. The calibration activity on GIADA PFM involve GDS, IS and GDS+IS. The calibration curves resulting from the present calibration activity are then correlated with those obtained on the GIADA instrument now mounted onboard Rosetta. We selected twelve different materials as cometary analogues. Each material was grinded to produce particles within four dimensional size bins (20-50 μm, 50-100 μm, 100-250 μm and 250-500 μm) and characterized by means of Field Emission Scanning Electron Microscopy and Energy Dispersive Spectroscopy (FESEM/EDS). According to previous calibration activity on GIADA, we estimated to be about one hundred the statistically meaningful number of particles to be shot for each sample type.

The lower limit grain size detectable by GDS is correlated to the optical properties of the dust grains crossing the laser curtain. Prelaunch calibrations established the lower limits, in diameter, equal to 120 μm for carbon particles, and 60 μm for silicate particles. In this extended calibration phase, we want to better characterize the range of size detectable by GIADA exploring particle sizes down to 20 μm. For this reason, we produced particles with sizes smaller than the GIADA expected detection limit.

2. The Electrostatic Micromanipulator

The need of manipulating such a large number of particles smaller than 500 μm prompted us to develop and test an innovative micromanipulation system able to capture, move and shoot particles of these sizes. The capture and the release of the particles with dimensions less than 500 μm is based on the electrostatic interaction with the micromanipulator probe.

2.1. Description of the device

The scheme of our device is shown in Fig. 1. The probe is constituted by two adjacent thin glass needles that are electrified producing a dipole. The distance between two tips, placed as shown in Fig. 1, is 3.0 ± 0.1 *mm*. A silvered copper wire, with section of 250 μm, is inserted into each needle; to prevent the entering of dust grains into the needles, we sealed off the tips used to pick up the particles. Connecting one of the two wires to the output of a High Voltage power Supply (HVS) and the other one to its reference (connected to the ground), an electric dipole between the two needles is created when the HVS is operating. Our laboratory tests showed that a short activation of power supply suffices to electrify the needles; in fact, once the probe is electrified, we need to switch off the HVS and then to approach the probe to the particle in order to pick it up.

Because of the different intrinsic dielectric proprieties of the materials chosen, we used two different HVSs, one able to reach voltages between 0 and -33 kV and the other able to reach voltages between 0 and $+33$ kV. Table 1

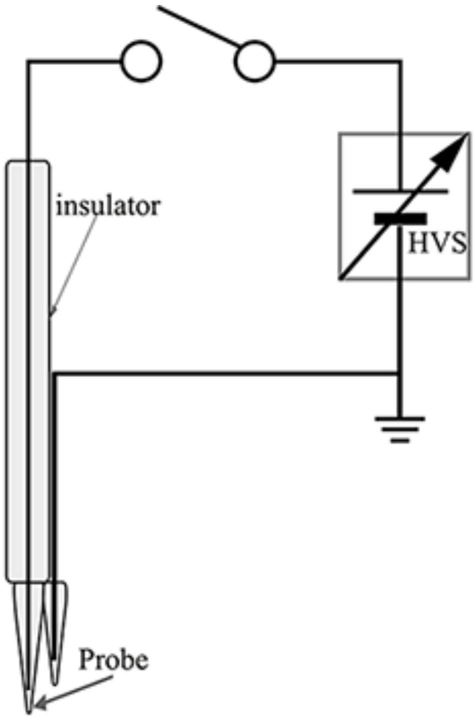

Fig. 1. Electric scheme of the Electrostatic Micromanipulator (EM) developed and realized in the "Laboratorio di Fisica Cosmica" – University Parthenope of Naples.

Table 1. The materials already tested with the EM. The cometary dust analogues are reported in black characters. Underlined materials were manipulated with negative voltages. Sodium hexaflorosilicate has been chosen as water ice simulant. It is used both as pure material and to cover particle grains of different composition.

Materials tested with EM
albite
corundum
enstatite
forsterite
silicate glass
kaolinite
pyrrhotite
serpentine
sodium hexaflorosilicate
talc

reports a list of ten already tested materials for which both positive and negative voltages are used. The size of the particles tested for these materials is in the range 50-500 μm.

2.2. Working principle

Switching on the HVS for few seconds, an electrostatic dipole is created between the two tips. Then, approaching the electrified probe to a particle ($\leq$ 500 μm), the dielectrophoresis force is able to capture it. The dielectrophoresis force acting on a particle is given by:

$$\mathbf{F} = \mathbf{n} \int_S \frac{1}{2} \epsilon_0 \epsilon_r (\mathbf{n} \cdot \mathbf{E})^2 dS \qquad (1)$$

where ϵ_0 is the permittivity of free space, ϵ_r is the relative permittivity, S is the surface of the particle, $\mathbf{n}$ is a unit normal vector of particle boundary and $\mathbf{E}$ is the electrostatic field, whose magnitude can be determined by using the Poisson law and the conservation of charge (Kawamoto 2009).

Once the particle is captured, we can shoot it simply by turn-on again the HVS with a voltage of the same sign used to capture the grain. In fact, when the particle lies on the tip of the electrified probe, the particle is charged with the same sign of HVS voltages used to electrify the tips. Therefore, once the HVS is reactivated, a repulsive force is be created between the probe and the grain, and consequently the particle is shot.

The voltages and the polarity we used to electrify the needles and to pick up particles depend on the material and size. The power supplies ranging between 0 and ± 33 kV allowed the manipulation and test with the selected ten different materials.

2.3. GIADA calibration set-up

The developed Electrostatic Micromanipulator is mounted on a X-Y-Z micrometric slides assembly equipped with a 360° rotational stage. It is placed on a optical bench between an optical microscope and GIADA PFM (see Fig. 2). This configuration, allows a full control on the EM probe positioning. In addition, it is possi-

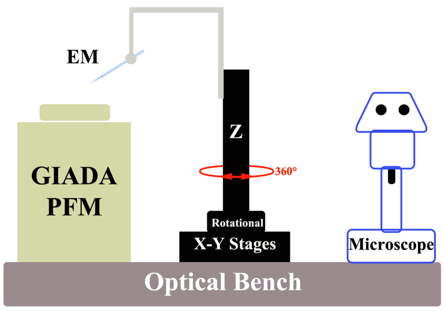

Fig. 2. Sketch of the setup used for the GIADA PFM calibration.

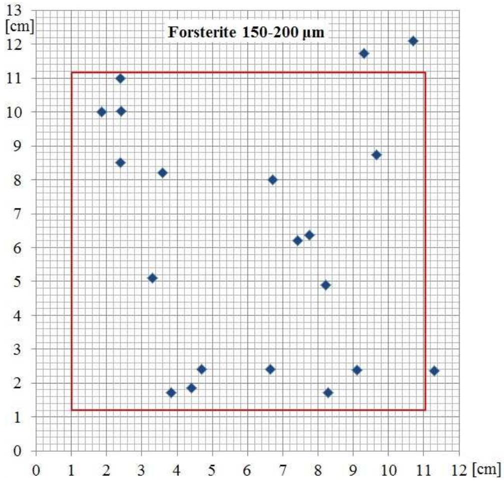

Fig. 3. Impact positions of twenty particles (blue points) of forsterite 150-200 μm shot by the EM during a test on GIADA STM. The red square represents the sensitive surface of the Impact Sensor.

ble to measure the captured particle dimension by means of an optical microscope mounted just beside the EM apparatus. This is necessary to correlate the signal detected by GIADA subsystems to the actual particle dimension.

The procedure used to shoot a particle in GIADA PFM is the following: (1) the particle is observed and measured by mean of the optical microscope; (2) the particle is captured by EM and moved by the micrometric handling system over GIADA PFM baffle; (3) the particle is shot by EM into GIADA.

All these operations are performed into a clean room Class 100, in order to avoid the contamination of the instrument sub-systems.

2.4. Electrostatic Micromanipulator Tests

Before using our electrostatic device for the extended calibration phase on the GIADA PFM, we performed some tests on the GIADA Structural /Thermal Model (STM) and on the IS-Development Model (DM). In particular, we carried out two kind of tests:

1. A series of tests on the GIADA STM simulating the calibration on GIADA PFM. We reproduced the set-up (see Fig. 2) to verify that the particles, shot by the EM, would actually impact the sensitive area of the IS. A graph paper covered by an adhesive and transparent film reproduces the IS surface and is able to stick the shot particles. A typical result of these tests is shown in Fig. 3: considering twenty particles shot, only three arrived outside the sensitive surface. We verified that, in the worst case, the particles impacting outside the IS sensitive area are 25% of the total shot grains.
2. A series of tests on the IS-DM (Fig. 4) to check that the particles shot by the EM are actually detected. Fig. 5 shows typical IS signals produced by a particle shot by the EM and impacting on the IS plate.

3. Conclusions

The Electrostatic Micromanipulator developed and realized in the "Laboratorio di Fisica Cosmica" (University Parthenope of Naples) was tested using particles of different dimensions (50-500 μm), composition (see Table 1) and optical properties. The laboratory tests, described in the present work, confirmed the proper functioning of the Electrostatic Micromanipulator devoted to capture, move and shoot the particles into the GIADA PFM. In the worst case, 75% of the particles manipulated/shot by the EM are detected by GIADA sub-systems.

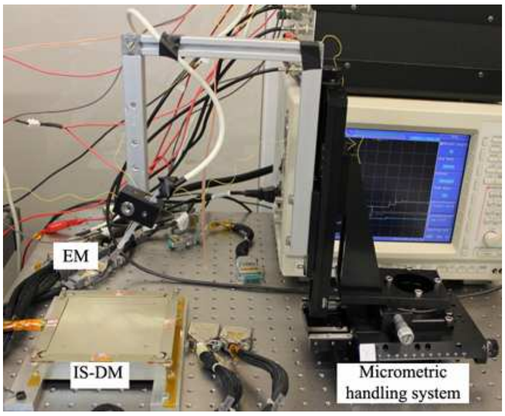

Fig. 4. Test using Electrostatic Manipulator on the IS-DM to verify that shot particles are detected by the sub-system.

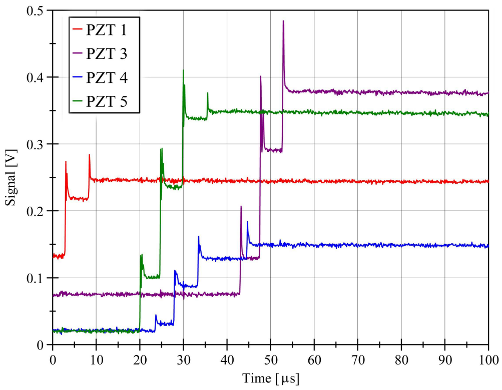

Fig. 5. Signals produced by IS sub-system as result of the impact of a forsterite grain particle (150-200 μm) shot by EM. The PZT2 signal is not acquired.

Taking into account this result, and considering that we want to obtain at least one hundred particle detections for each of the twelve materials selected as cometary dust analogues, we will have to manipulate/shoot about one thousand and six hundred particles to build the new calibration curves for GDS and IS.

The need of manipulating such a large number of particles makes the Electrostatic Micromanipolator very critical for the calibration of GIADA PFM, because a single device is able to capture, manipulate and shoot single particles in the range of needed sizes ($20-500$ μm). Moreover, the EM installed on the X-Y-Z movimentation stages and placed between the microscope and GIADA PFM, simplifies the experimental procedures necessary to obtain the calibration curves.

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