Nuclear Inst. and Methods in Physics Research, A 908 (2018) 269–276

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Trajectory measurements for individual dust particles on the colorado dust accelerator

William Goode [a,b,*], Tobin Munsat [a,b], David James [a,b,c], Zach Ulibarri [a,b,c]

[a] Department of Physics, University of Colorado, 2000 Colorado Ave, Boulder, CO 80309, USA
[b] Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT), University of Colorado, Boulder, CO 80303, USA
[c] Laboratory for Atmospheric and Space Physics, 1234 Innovation Drive, Boulder, CO 80303, USA

ARTICLE INFO

Keywords:
Cosmic dust
Accelerator
Particle detector
Planetary science
Dust instrument
Beam control

ABSTRACT

The Dust Coordinate Sensor (DCS) is a dual detector instrument located on the beamline of the 3 MV hypervelocity dust accelerator at the University of Colorado Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT). This instrument non-destructively measures the three-dimensional trajectories of charged, hypervelocity (3–8 km/s), micron-sized dust particles in flight by utilizing the image charge induced on grids of wire electrodes. Where previous peak detection was typically limited to dust particles carrying charges $>\sim$ 100 fC, new signal processing techniques developed for DCS allow for effective trajectory measurements on particles carrying charges as small as 6 fC. The new signal processing also effectively eliminates false signal detections completely. The position measurements are matched by timestamp to the charge and velocity for each launched dust particle. Verification of the system was performed with independent impact location measurements on a target placed in the beamline. These measurements agree to within 1 mm^2 of the predicted locations using DCS trajectories. This study demonstrates the capability of the instrument including new processing methods. Precise trajectory measurement along the beamline enables new options for instrument calibration, scientific experiments, and improvement of the accelerator performance.

1. Introduction

Cosmic dust found throughout space provides information on the history and dynamics of the universe. Micrometeorite impacts by interstellar dust on the sub-micrometer to micrometer size scale, whether on the surface of an airless body or space-borne instruments, are useful phenomena for extracting information on a particle's characteristics (e.g. chemical composition, size, and trajectory) as well as on the environment in which it is found (e.g. dust flux) [1].

Dust particles in space typically impact at hypervelocities leading to a plasma produced by the ionization of both the impactor and the impact surface material [2]. Space-borne instruments based on some form of impact target use impact ionization for *in situ* measurements. Utilizing time of flight mass spectroscopy, the ions from the plasma cloud reveal information on the dust particle's composition. For many dust instruments, impact ionization is a key feature of the operational design [3,4]. Other dust instruments, while not directly analyzing impact ionization, detect its effects in order to understand general aspects of the dust environment. This may involve counting each impact event in order to measure the density of dust particles throughout different regions of the solar system [5]. The dust environment also plays a significant role in space weathering. Surfaces exposed to space accumulate dust impacts over time. For example, the Long Duration Exposure Facility (LDEF) remained in low earth orbit for nearly six years in order to study the effect of space weathering on various surfaces and materials. After being retrieved from orbit, thousands of impact-related features were characterized and documented [6–8]. By replicating the measured effects of dusty plasmas and impacts occurring in space we can better understand the environment in which such measurements are taken.

Laboratory experiments related to the study of dust impacts are performed using the 3 MV hypervelocity dust accelerator [9] at the Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT) at the University of Colorado, Boulder. Schematically illustrated in Fig. 1, this accelerator utilizes a static electric potential generated by a Pelletron chain induction system [10]. Electrostatic dust accelerators with the capability to launch micron and sub-micron diameter charged dust particles were first built in the early 1960s. These include accelerators at Space Technology Laboratories in Redondo Beach, California and at the Max Planck Institute in Heidelberg, Germany [11–13].

The dust particles are charged in a $\sim$ 1 cm^3 volume reservoir by contact with a needle kept up to 20 kV as described by Shu et al. [9]. This technique results in charge levels approaching 10% of the field-emission limit, which varies from particle to particle. Once charged, each particle

* Corresponding author at: Department of Physics, University of Colorado, 2000 Colorado Ave, Boulder, CO 80309, USA.
E-mail addresses: william.goode@colorado.edu (W. Goode), tobin.munsat@colorado.edu (T. Munsat), david.james@lasp.colorado.edu (D. James), Zachary.Ulibarri@colorado.edu (Z. Ulibarri).

https://doi.org/10.1016/j.nima.2018.08.075
Received 17 April 2018; Received in revised form 7 August 2018; Accepted 23 August 2018
Available online xxxx

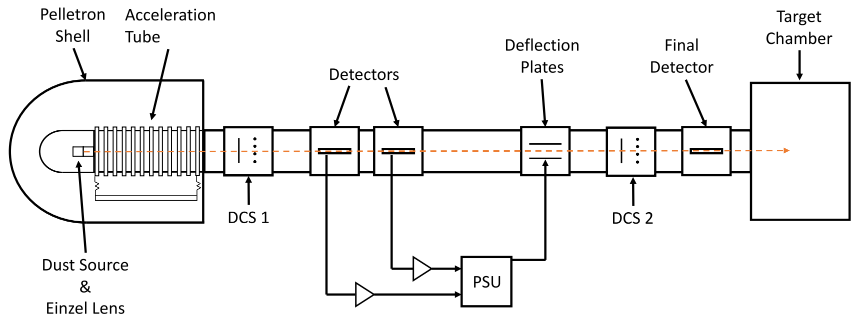

Fig. 1. Schematic of the hypervelocity dust accelerator. The particles contained in the dust source are charged before entering the acceleration tube. The Einzel lens pre-focuses the particle beam using a shaped static electric field. The first two detectors measure the particle charge and velocity, which the PSU utilizes for down selection. The deflection plates are grounded by a pulse from the PSU, allowing individual particles to continue towards the target chamber. The final detector verifies the down-selection by the PSU and deflection plates. The Dust Coordinate Sensor (DCS) measures particle trajectory using two in-beam detectors, DCS 1 and 2.

is accelerated down the beamline through a series of three image charge detectors before reaching the target chamber. Particle velocity is measured using time-of-flight between the first two detectors [9]. Particles reach velocities ranging from approximately 1.5 to 100 km/s with diameters ranging from tens of nm to ∼ 5 μm.

Since the size of individual particles from a given dust source are typically inhomogeneous, the characteristics (charge, velocity, etc.) of each accelerated particle cannot be predetermined. Therefore the particle beam itself consists of random discrete dust events. Even in cases where the dust itself is monodispersive (e.g. Burchell et al.) [14], the charging method may lead to a distribution of charge-to-mass ratios and thus final accelerator velocities.

The Particle Selection Unit (PSU) down-selects in order to provide the experimenter control over the parameters of particles reaching the target [9]. The PSU utilizes deflection plates, otherwise known as the gate, that generate a static transverse electric field diverting particles out of the beamline as a default state. The gate is opened at the precise time in order to allow a desired particle to pass through to the final detector and target chamber. This is enabled by a field programmable gate array (FPGA) that performs fast real-time calculations based on signals generated by the image charge detectors [15].

Measurements of the particle position (x,y) perpendicular to the beamline direction (z) must be made by a dedicated set of detectors. This has been done in the past on a similar dust accelerator by a position detector at the Max Planck Institute in Heidelberg, Germany [16]. This detector uses charge induced by a particle on four pairs of parallel plates. The system was calibrated to use the amplitude ratios to compute particle position at a single location on the beamline. However, in order to determine a particle's trajectory, and thereby its position anywhere along the beamline, position measurements must be made at more than one location.

The Dust Coordinate Sensor (DCS) at the Colorado dust accelerator was developed for the purpose of providing similar particle position information along the beamline, which has been unknown until recently. This instrument consists of two detectors installed 4 m apart on the beamline. Each detector measures two-dimensional position in the plane orthogonal to the beamline. This new instrument is capable of measuring three-dimensional trajectories of each dust particle in flight. This added capability allows us to profile the particle beam as well as predict individual particle impact locations with high precision.

The design, calibration, and testing of the DCS detector was previously conducted by Northway et al. [17]. In this paper, we describe the work based on such detectors that leads to a three-dimensional dust particle trajectory measurement system for a dust accelerator.

2. Method of measurement

DCS is an in-beam instrument that uses charge induction on a series of eight 0.48 mm thick wire electrodes to measure particle position.

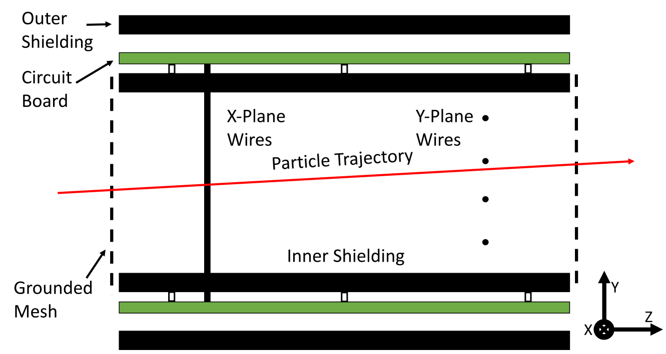

Fig. 2. Cutaway schematic diagram of a single DCS detector. Wire electrodes in the first wire plane run vertically and measure x-position while the wires in the second plane run horizontally and measure y-position. The wire planes are separated by 5.1 cm along the beam direction.

The stainless-steel wire electrodes are placed within a 2.5 × 2.5 cm square channel mounted on a removable 6 inch flange on the beamline. The wire electrodes are arranged into two separate planes of four wires orthogonal to the direction of the beamline. The first wire plane consists of four vertical wires while the second plane consists of four horizontal wires all spaced by 5 mm. The wire planes themselves are separated by 5.1 cm from each other in the z-direction. Together they form 25 regions through which a particle might fly. The dust-beam diameter is ∼10 mm peaked in the center due to focusing by in-beam electrostatic optics. Each DCS detector has an open area of ∼ 80%. A detailed description of the mechanical design of the individual DCS detectors is presented in Northway et al. [17]. A schematic of the detector design is shown in Fig. 2. Throughout this paper, we later refer to a set of four vertical or horizontal wires as a "wire plane", each DCS detector consisting of two wire planes simply as a "detector", and the system consisting of both detectors as the "instrument".

As each particle travels through the wire planes, it induces image charges on the wire electrodes. The greatest induced charge occurs on the nearest wires, and the ratio of peak induced charge between the two nearest wires is a unique function of particle position. This method of charge-dividing was first applied by Auer et al. to measure the trajectories of charged cosmic dust particles [18]. The vertical wire plane is used to determine the horizontal (x) position while the horizontal wire plane is used for the vertical (y) position. Each wire electrode is connected to a separate charge sensitive amplifier (CSA) so that the induced charge on each wire electrode can be measured. This concept is illustrated in Fig. 3. The CSAs are based on a OPA356 operational amplifier, with sensitivities ranging from 1.15×10^{13} to 1.28×10^{13} V/C. The CSAs were calibrated individually using a charge injection capacitor and exhibit typical noise levels of 4 mV, corresponding to 0.3 fC.