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Development of in-situ micro-debris measurement system

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Abstract

The in-situ debris environment awareness system has been developed. The objective of the system is to measure small debris (between 100 μm and several cm) in orbit. The orbital distribution and the size distribution of the debris are not well understood. The size distribution is difficult to measure from the ground, although the size distribution is very important for the risk evaluation of the impact of debris on spacecraft. The in-situ measurement of the size distribution is useful for: (1) verification of meteoroid and debris environment models, (2) verification of meteoroid and debris environment evolution models, (3) real time detection of unexpected events, such as explosions and/or collisions on an orbit. This paper reports the development study of the in-situ debris measurement system and shows demonstration experiments and their results to describe the performance of the micro-debris sensor system. The sensor system for monitoring micro-debris with sizes ranging from 100 μm to a few mm must have a large detection area, while the constraints of space deployment require that these systems be low in mass, low in power, robust and have low telemetry requirements. For this reason, we have been developing a simple trans-film sensor. Thin and conductive stripes (copper) are formed with fine pitch (100 μm) on a thin film of non-conductive material (12.5-μm thick polyimide). A hypervelocity micro-particle impact is detected when one or more stripes are severed by perforation of the film. We designed a debris detector specialized for measuring the micro-debris size and collision rate. We then manufactured and calibrated the detector.

Keywords: Space debris; Meteoroid; Sensor

1. Introduction

JAXA's "Space Environment Standard" and "Debris Defense Standard" states that debris of 100 μm to several mm in size would cause a spacecraft to experience critical failures and other trouble. For instance, the impact of such debris can cause serious damage to the wire harness and other equipment of the spacecraft. JAXA has learned a lesson about the risk of micro-debris from an incident involving the JAXA satellite ADEOS-II (Midori-II). According to a verification experiment conducted by JAXA, the impact of an object larger than 300 μm at a velocity of 4 km/s damaged the second-layer harness, leading to a continuous electrical discharge, and resulting in a short circuit due to carbonization (JERG-2-144-HB001, Space Debris

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Protection Design Manual, JAXA, 2009). The results indicate that even small debris of 100 μm to a few mm (i.e., micro-debris) can cause serious damage to wire harnesses and other equipment.

However, the collision rate of micro-debris with a size of 100 μm to several mm is hard to predict due to a lack knowledge regarding the debris distribution in orbit because such micro-debris is too small to be observed by ground telescopes and too low flux to be detected by existing space borne dust detection technology. Measurements of the flux of such micro-debris have been performed by sample-return missions with long-term exposure to space but we are currently unable to take real time data leading to detailed orbital information. In addition, to measure the size distribution, we have studied a system combining an optical telescope and a dust detector in orbit for in-situ measurement with JAXA's collaborators. As it stands now, an in-situ optical observation system is under conceptual study, while an in-situ dust sensor is already in the FM (Flight model) development phase.

In-situ measurement data might be useful for:

- Verification of space debris environment models,
- Verification of evolution models for the space debris environment, and
- Real time detection and assessment of the influence of unexpected events, such as explosions in orbit (e.g., ASAT (Anti-Satellite Test) and satellite collisions), on the space environment.

A model of the micro-debris flux in orbit is necessary for the risk assessment of debris collisions, but current models have a double-digit discrepancy (S. Fukushige et al., 2007). Under these circumstances, measuring environmental data and accurately assessing the collision rate is urgently needed in order to mitigate the risk of micro debris collisions in satellite operation. The ability to observe debris is necessary and indispensable to solve such a problem. Thus, in-situ observation is very necessary in orbit.

While many sensors have been developed, thin film detectors had been investigated by Hörz et al. (1995) and Christiansen et al. (2006). Many micro-debris monitoring sensors have been developed to observe meteoroids, and more than ten types are available (Klinkrad, 2006). Conventional systems are not suitable for the measurement of debris larger than 100 μm in size. In addition, many hypervelocity impact tests are required to correlate the changes produced in sensors with the impact parameters (velocity, particle diameter, and material). For these reasons, we have developed a sensor that works on the basis of the principle proposed by the Institute for Q-shu Pioneers of Space (iQPS) and IHI Corporation (US8564430, CA 2712411, CN ZL200980108349.4, UA 94873, JP 5492568, EA1906). A detector based on a similar system is being investigated in the USA (Orbital Debris Quarterly News, 2008 and 2012).

We are aiming to standardize micro-debris measurement for use by engineers. The sensor is specialized to measure micro-debris size and collision rate. These are especially significant in terms of risk assessment because we are focusing on simplification, weight reduction, expansion of the detection area, and cost reduction. In this paper, we report that development models of this sensor were manufactured and micro-debris collision experiments were performed using the models for practical application.

2. Concept of in-situ micro-debris sensor

As mentioned in the previous section, the objective of the in-situ micro-debris sensor is measurement of debris flux in the size range of 100 μm to a few mm. Conventional in-situ measurement sensors for micro-meteoroids/micro-debris measure physical phenomenon (vibration, plasma, electromagnetic waves, and so on) which are induced by the impact energy of hypervelocity micro-meteoroid/micro-debris collisions on the sensor (Goldsworthy et al., 2002).

Such sensors are unsuitable for enlarging the measurement area and for the measurement of micro-debris from 100 μm to a few mm in size. Moreover, many hypervelocity impact experiments (parameter surveys) are necessary to relate the phenomenon that occurred in the sensor to the impact parameters (velocity, size, and composition). Therefore, we adopted simpler principle for hypervelocity particle detection, which is described in Kitazawac et al. (2009). Here, the measurement method is introduced briefly.

The sensor itself is a thin film of a nonconductive material such as polyimide, on which thin conductive stripes are formed in parallel, the stripe width is about 50 μm and the spatial separation is about 100 μm, as shown in Fig. 1. When a micro-debris particle with an effective diameter near or larger than the spatial separation of the stripes (here about 100 μm) collides with the sensor film at a velocity sufficient to penetrate it, one or more of the stripes are cut and become nonconductive. This is known as a trans-film micro-debris sensor. Debris impacts can be detected by monitoring the electrical conductivity of the stripes. This sensor system measures the size of the incident micro-debris particle by detecting the number of severed stripes.

The adoption of this method has the following advantages:

- Hypervelocity particles with sizes of 100 μm to a few mm which conventional sensors can barely detect can be measured.
- The sensor configuration is simplified and the effort and cost involved in calibrating the sensor can be reduced.
- The sensor area can be enlarged and the weight can be reduced, which leads to secure flight opportunities.
- Using two layers of the sensor, the sensor system can measure the velocity (velocity and arrival direction) of the incident micro-debris.