Acta Astronautica xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Acta Astronautica

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

Growth in the quantity of debris in Space as AN effect of mutual mechanical collisions of various types

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ARTICLE INFO

Keywords:
Dangerous space objects
Orbital debris
Space systems
Mutual interactions
Impact
Tensometry
Measurement

ABSTRACT

Estimates are determined of the potential consequences of mutual collisions of dangerous space objects both among themselves and with operating space systems. Research extrapolating the existing objective estimates and supervision of pollution in low Earth orbits shows the probability of catastrophic growth in the number of objects and orbital debris in low orbits leading to the practical impossibility of further peaceful scientific exploration of space. The development of methodologies and technologies regarding the comprehensive investigation of shock impacts on space objects and systems becomes the actual task for the creation of conditions for the safe development of peaceful space explorations. Research involving the collision processes, including the dynamics and associated consequences, developing means and pathways of protection for spaceships, protection of structures and systems from the influence of high-speed objects, means and methods to remove debris from space, and the use of dangerous objects. The technology of measurements with applications in tensometry provides data acquisition concerning the shock impulse in a wide range of collision conditions, and ensuring a physical and constructive variety of the impacting objects is considered.

1. Introduction

The goal in the development process of space equipment is to discover and explore space for human welfare and progress. It is recognized that the achievement of this purpose becomes complicated not only by the natural phenomena of space debris in the process of formation of the universe (asteroids, comets, meteorites) but also from threats of the technogenic contamination of space (the report of the United Nations (UN) Secretary General “Action of space activity on environment” of December 10, 1993). The results of research regarding the extrapolation of existing objective estimates and supervisions of a contamination of low Earth orbits (LEO) show the probability in the catastrophic growth in the number of objects or orbital garbage in LEO up to the practical impossibility of further development in space. In the years 1999, 2007 and 2013, reports regarding space fragments and recommendations of a scientific and technical subcommittee (STSC) of the UN committee about the use of space in the pursuit of peace (COPUOS) were made [1]. Therefore, the problems that connect the influence of different impacts from dangerous space objects (from micrometeorites [1] up to spacecrafts, systems [2,3] and asteroids) have to be exposed to carefully and comprehensively investigate possible solutions [4,5]. The results of this research must consider the production technologies of space systems and their exploitation when developing models for space exploration [1]. Researching the impact processes and the associated dynamics and consequences are necessary when developing methods to protect spacecraft and systems from the influence of high-speed objects (patent RU 2294866, patent US 6647855A) in addition to methods to remove and utilize dangerous objects from space [6–12]. Consideration of the impact processes is important and perspectives are recognized in works with purposes of developments for near and far space exploration, in the research of planets, in the implementation of measurements of the Earth for protection from asteroids and when developing technologies to demolish dangerous space objects [13–15]. Thus, developing methods and technologies to comprehensively study the shock interactions on space objects becomes an actual task for the creation of conditions for the safe development of space in peace purposes. Research must provide a wide range of conditions for impact and a variety of physical and design features for colliding objects. One effective method to perform experimental and theoretical research of the interaction process is tensometry. This technology allows the investigation of the detailed dynamics of the impact process and the features of the realized impact impulse in order to accurately determine the forces and kinematic parameters of the impact process [15–19].

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http://dx.doi.org/10.1016/j.actaastro.2016.11.003
Received 15 September 2016; Received in revised form 25 October 2016; Accepted 1 November 2016
Available online xxxx

2. Experimental details

The technology of tensometry or strain measurements contains the technology of measurement with the application of piezoelements as a private option. Piezometric technology is considered the most efficient [15–17] since it allows the acquisition of data on changes in device acceleration in time as well as other kinematic parameters by applying precise integral operations. Below, a diagnostics technique is presented [18] along with one of the testing methods [19], both based on piezometry technology. The method uses a high-frequency piezoelectric accelerometer ASM-4 according to patent RU 1741082 which is mounted according to patent RU 1799744. Continuous wired electric connection with the accelerometer up to the end of the process is realized under the conditions that the motion of the object is in the direction of the measuring rod. The linearity of the transformations for accelerations up to 10^7 m/s^2 was established experimentally. The piezoelectric accelerometer is installed on either the object or the measuring rod close to the zone of interest. In each case, the piezoelectric accelerometer registers the acceleration. A technical problem in the experiment is data acquisition regarding the size and change in time of the kinematic parameters of an element including acceleration (dV/dt (t)), speed (V (t)) and position (X (t)) of the object.

The piezoelectric accelerometer cannot always be hardwired to the registrar for studying space objects. It is then suggested to attach the piezoelectric accelerometer on a measuring element in vitro. Under the influence impacts from objects, the element acquires a velocity in the direction of impact, which in turn causes a displacement of the piezoelectric accelerometer fixed to the element.

2.1. Simulation and analysis

Let us consider the example of a continuous electrical connection between the recording unit and the accelerometer until the end of the intensive acceleration phase of the measuring rod. This particular example of the measuring piezometric technology is realized under element acceleration in a gas-dynamic impulse device and the corresponding impact with a measuring rod. The element is accelerated in the barrel of a gas-dynamic impulse device up to a defined velocity V_O. Then, an impact occurs with a measuring rod that is fixed along the direction of the element motion. In some cases, cutters of diffractors are required. The rod with a fixed piezoaccelerometer is either mounted on a light rest or suspended. The wires to the accelerometer are connected with the signal line of electrical connection channel and the recording unit. The sweeping begins either with a light barrier or using mechanical blocking and a synchronization block. The element and the rod are moving together with the same velocity V_m in the end of the impact. To process the oscillogram, the element velocity, V_m, must be known and is thus registered in the experiment using screens and frequency meters. For visual control of the impact and the acceleration process, high-speed optical registration in performed with transmitted or reflected light and in some cases a regulated electrical impulse highlight is used. Digital single- and multi-ray oscilloscopes are used as recording units.

An example of the information obtained regarding the tested process is shown in Fig. 1.

Electrical signals measured by the accelerometer are proportional to the acceleration of the free face of the rod. The shape of the acceleration impulse determines the registered features on the oscillogram's deceleration history of the rod's elastic component. The mechanical impact on the structural elements of a is registered with modernized test types. Each test type is chosen based on required materials and the design features of the tested object, as well as the impact intensity during its function. The experiment predicts acceleration and deformation of an M2 copper rod with a dimeter of 6.1 mm and a length of 25 mm, with impact by a rigid element made of hardened steel at a velocity, V_O =169 m/s. Optical registration is performed with transmitted light at a frequency of 167,000 frames/second. The oscillogram registers the acceleration history of the rod rear face (shown at the right in the photo and in the oscillogram) where the piezoaccelerometer is mounted in the time range from the moment the front face is impacted by the element until there is no relative motion of the rod with respect to the element. In Fig. 1, optical registrations are correlated to acceleration values of the rod for 8 moments, t_i, in this time range. After the impact, the rod (Fig. 1) is measured in order to determine the magnitude and longitudinal profile of the residual plastic deformations. The diameter of the front edge, d_{np}, and the length of the plastically undeformed component, $(l_e)_m$, are determined. The level of residual plastic deformations of the element front face is also evaluated. The oscillograms and optical registrations are processed using the described methodology [17]. An example of the results is presented in Fig. 2.

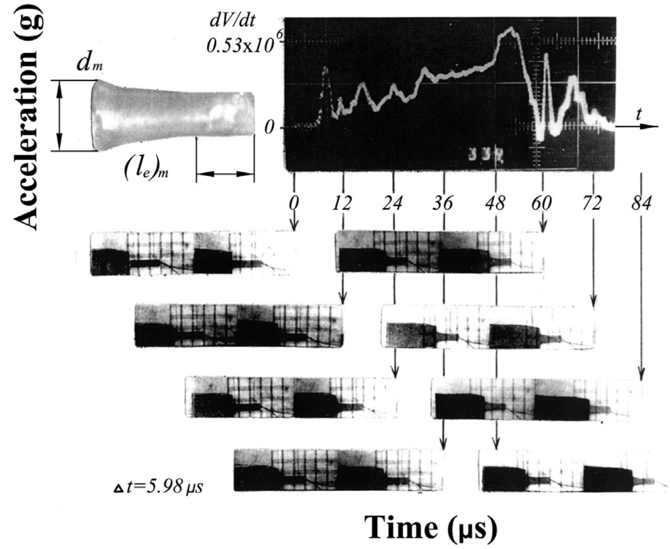

Fig. 1. The most significant data registered in the experiment.

This example illustrates the comparison between the values of the length of the current rigid portion of the rod, measured in the optical registration $(l_e)_{op}$, and its calculated value from the characteristic deceleration history of the front face on the oscillogram, $(l_e)_{os}$. The confidence interval of absolute value, $(l_e)_{op}$, is ± 1.3 mm and is shown on the graph as an interval with a circle in the middle. The confidence interval of $(l_e)_{os}$ for the current experimental conditions is 0.9 mm and is shown as an interval with the crossing in the middle. The analysis of

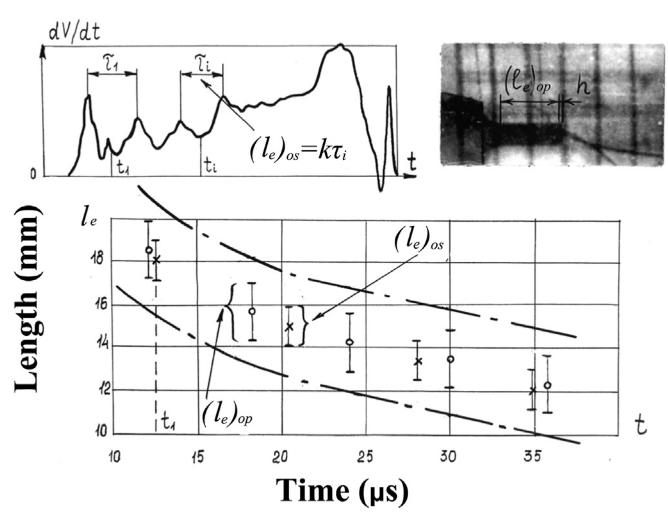

Fig. 2. Results showing how the length of the elastic rod part in each moment of time is calculated from the acceleration history and optical registration.