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A new advanced railgun system for debris impact study

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Abstract

The growing quantity of debris in Earth orbit poses a danger to users of the orbital environment, such as spacecraft. It also increases the risk that humans or manmade structures could be impacted when objects reenter Earth's atmosphere. During the design of a spacecraft, a requirement may be specified for the surviv-ability of the spacecraft against Meteoroid / Orbital Debris (M/OD) impacts throughout the mission; further-more, the structure of a spacecraft is designed to insure its integrity during the launch and, if it is reusable, during descent, re-entry and landing. In addition, the structure has to provide required stiffness in order to allow for exact positioning of experiments and antennas, and it has to protect the payload against the space environment. In order to decrease the probability of spacecraft failure caused by M/OD, space maneuver is needed to avoid M/OD if the M/OD has dimensions larger than 10cm, but for M/OD with dimensions less than 1cm M/OD shields are needed for spacecrafts. It is therefore necessary to determine the impact-related failure mechanisms and associated ballistic limit equations (BLEs) for typical spacecraft components and subsys-tems. The methods that are used to obtain the ballistic limit equations are numerical simulations and la-borato-ry experiments. In order to perform an high energy ballistic characterization of layered structures, a new ad-vanced electro-magnetic accelerator, called railgun, has been assembled and tuned. A railgun is an electrically powered electromagnetic projectile launcher. Such device is made up of a pair of parallel conducting rails, which a sliding metallic armature is accelerated along by the electromagnetic effect (Lorentz force) of a cur-rent that flows down one rail, into the armature and then back along the other rail, thanks to a high power pulse given by a bank of capacitors. A tunable power supplier is used to set the capacitors charging voltage at the desired level: in this way the Rail Gun energy can be tuned as a function of the desired bullet velocity. This facility is able to analyze both low and high velocity impacts. A numerical simulation is also performed by using the Ansys Autodyn code in order to analyze the damage. The experimental results and numerical simulations show that the railgun-device is a good candidate to perform impact testing of materials in the space debris energy range.

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1. Introduction

Since the beginning of space age on 4 October 1957 (launch of Sputnik I), there have been more than 4,900 space launches, leading to over 18,000 satellites and ground-trackable objects currently in Earth orbit. For each satellite launched, several other objects are also injected into orbit, including rocket upper stages, instrument covers, etc. This causes an uncontrolled growth of objects in orbital environment, see Schneider (1990) and McKnight (1991). Some catastrophic accident suggests the need to protect spacecrafts and satellites against M/OD impact (M/OD with dimensions less than 10 cm) that could damage and, in the worst case, destroy them as indicated by Piattoni et al. (2014), Pigliaru et al. (2014), Piergentili et al. (2014), Santoni et al. (2013). This protection could be assured by shielding technologies such as the Whipple Shield, a kind of shield that protects space structures against hypervelocity impacts as indicated by D. Palmieri, M. Faraud et al. (2001). It is therefore necessary to determine the impact-related failure mechanisms and associated ballistic limit equations (BLEs) for typical spacecraft components and subsystems as reported by Eric L. Christiansen, Justin H. Kerr (2001). The methods that are used to obtain the ballistic limit equations are laboratory experiments and numerical simulations as indicated by Faraud M, Destefanis (1999). To make ballistic tests it can use different methodologies depending on the energy of impact to be achieved ; for example, for low energies of impact Micheli D., Gradoni et al. (September 2010) and D.Micheli et al. (September 2011) performed ballistic tests using a coilgun. In order to perform an high energy ballistic characterization of layered structures, a new advanced electromagnetic accelerator called railgun, developed by Micheli et al. (2014, 2016), has been assembled and tuned. A railgun is an electrically powered electromagnetic projectile launcher. In this work, we demonstrate the possibility of using the railgun as a system for conducting hypervelocity impact tests. Numerical simulation and experimental tests were carried out on two types of shielding structure, an aluminum monolithic shield and a WS structure composed of an aluminum wall and a composite material bumper (multilayered structure).

Nomenclature

BLE	Ballistic limit equations
BWS	Break Wire System
CFRP	Carbon Fiber Reinforced Materials
CNT	Carbon Nanotube
M/OD	Meteoroid / orbital debris
MWCNTs	Multiwall Carbon Nanotubes
RG	Railgun
WS	Whipple Shield

2. Materials and methods

2.1 Sample manufacturing

The impact tests were conducted on two types of target: a monolithic plate aluminum alloy 7075 (Aluminum) and a WS type structure with a composite material bumper (multilayered structure). The composite materials are manufactured by integrating several layers of Kevlar fabrics and carbon fiber ply within a polymeric matrix (epoxy resin) also reinforced by carbon nanotubes at 1wt% versus the matrix. The polymeric matrix is the bi-component epoxy resin Sika Biresin CR82 with the hardener CH 80-2 with density 1.15 g/cm^3 and viscosity 600 mPas at 25° C. The MWCNTs are the NC7000 (average diameter around 9.5 nm, average length 1.5 µm, purity 90%, surface area 250-300 m^2/g) supplied by NANOCYL. The layered carbon fiber reinforced polymer (CFRP)+Kevlar structure is made of six layers of carbon fiber (biaxial woven roving 0°-90°) and two of Kevlar fabrics. Manufacturing is performed by taking care to overlap one layer upon the other by following the scheme (0°÷90°), (+45°÷ −45°), (0°÷90°), two layers of biaxial