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Damping performance of bean bag dampers in zero gravity environments

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A B S T R A C T

Bean bag dampers (BBDs), developed from impact damping technology, have been widely applied in engineering field to attenuate the vibration of a structural system. The damping effect of a BBD on vibration control in ground gravity environments is good, but its performance in zero gravity environments is not clear, and there are few studies on it. Therefore, the damping effect of BBDs in zero gravity environments was investigated based on the discrete element method (DEM) in this paper. Firstly, a three-dimensional DEM model of a BBD was established, and the damping effects of the single degree of freedom (SDOF) systems with BBDs and non-obstructive particle dampers (NOPDs) in zero gravity environments were compared. Moreover, the influences of the diameter of the inner ball, the tightness of BBD, the vibration frequency of SDOF system and the gap between BBD and cavity on the vibration reduction effect of BBD in zero gravity environments were also studied, and the results were compared with the system with BBD in ground gravity environments. There are optimum ranges of the diameter of the inner ball, tightness and gap for BBD, and the effects of these parameters on the damping performances of BBD in gravity and zero gravity environments are similar in evolving trends, and the values are without big differences in the optimum ranges. Thereby the parameter selection in BBD design in zero gravity environments is similar to that in gravity environments. However, the diameter of BBD should be a slightly larger than the size of the cavity when the structures with BBD work in zero gravity environments. The BBD is supposed to be picked tightly when the vibration frequency is high, and the BBD has better to be picked more tightly in zero gravity environments. These results can be used as a guide in the design of BBDs in zero gravity environments.

1. Introduction

Passive vibration damping is a common approach used to suppress vibrations in mechanical and structural systems due to its simplicity and low energy consumption [1]. A particle damper (PD) is an effective passive control device which is developed from impact damper. The device dissipates energy through wall-particle and particle-particle inelastic collisions and friction [2–8]. PDs have been widely used due to their conceptual simplicity, potential effectiveness over a broad frequency range as well as temperature and degradation insensitivity, and low cost [9–12]. Researchers have developed many different kinds of PDs such as bean

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bag dampers (BBDs), non-obstructive particle dampers (NOPDs), multi-unit impact dampers, piston-based particle dampers and fine new particle impact dampers (FPIDs), BBDs and NOPDs are the common types which often be used [5–16].

A BBD is an effective vibration control technique consisting in a resilient bag filled with particles inserted into a cavity within or attached to a vibrating structure. The damping characteristics of BBDs in harmonic excitation were studied by Popplewell et al. when they researched the vibration of boring bar in the early 1980s, and a semi-empirical impact model was developed according to the experimental data [14,17]. The impact damping mechanism of BBDs was further researched by Chen et al. based on the classic collision theory, and the new concepts, contact periodic ratio and effect factor were introduced [18]. Many experimental studies on BBDs were conducted, and the parameters such as excitation force, natural frequency of primary system, size and mass of BBDs were analyzed [19–21].

A NOPD is composed of a container filled with ceramic or metal particles, and numerous studies have been done, Wang et al. established the theoretical model of NOPDs based on the simplified endochronic theory, Wu et al. built the NOPDs' theoretical model according to the multiphase flow theory of gas-particle and Cui et al. constructed the turbulentlike model of NOPDs, all of them analyzed the energy dissipation of NOPDs quantitatively [22–25]. Michon and darabi studied the damping performances of NOPDs with soft hollow particles and polymeric particles respectively [26,27], Sachez et al. researched the effects of the particle shape and fragmentation on the response of NOPDs [28]. So far, the influences of mass ratio, particle size, levels and directions of excitation, etc. on NOPDs in gravity environments were studied [2–10,22–33].

The PDs' damping performance in ground gravity environments is good, and the researches about PDs are mainly carried out in this condition [2–10,12–33]. However, the dynamic behavior of particles in zero gravity environments may be significantly different from that in ground gravity environments because of the lack of gravity. Many structures and instruments working in space such as satellite solar panels, gyroscope of orbiter and spacecraft structures are in the zero gravity environments. To apply PDs to space structures, the experimental studies were carried out by a group from California Polytechnic State University. They initiated a parabolic flight test under CP7 project with the NASA Reduced Gravity Flight Opportunity program to characterize NOPDs in a micro-gravity environment, but the experiment failed to prove their hypothesis, because the complete data to calculate damping quality factors were not obtained [33]. Yao and Chen [11] have researched the behavior of NOPDs in zero-gravity environments by the discrete element method (DEM), and a cross-shaped spoiler to raise the damping performance of NOPDs was introduced.

In this work, we used the discrete element method (DEM) to establish the three-dimensional model of BBDs and investigate the damping effect of BBDs in zero-gravity environments. The DEM is briefly described in Section 2. In Section 3, the DEM model of BBDs is established and verified by comparing with the experimental results. In Section 4, the damping performances of NOPDs in gravity and zero gravity environments are analyzed, and the damping effects of NOPDs and BBDs in zero gravity environments are compared. The effects of the inner ball diameter, the tightness, the vibration frequencies and the gap between BBD and cavity on the damping performance of BBDs in zero gravity environments are studied and compared with that in ground gravity environments in Section 5 and the conclusions are summarized in Section 6.

2. The discrete element theory and method

DEM is a discontinuous numerical method proposed by Cunall and Strack [34]. Using DEM, the parameters and properties of particles, not only single particle, but also overall particles could be studied in depth. It offers a potential for a deeper understanding of the particle damping mechanism [35].

Particle–particle and particle–structure contacts can be detected in DEM. The normal contact can be simplified as a spring-damping component, while the tangential contact can be simplified as a spring-damping component and a sliding frictional component, as shown in Fig. 1. When the tangential force between two particles is larger than the static friction force, the relative sliding action happens. Otherwise, the spring-damping component works [36].

The contact stiffness is a linear model in this work based on the Hertz contact theory. The Hertzian contact relates a nonlinear normal force F_{nk} as the function of the normal displacement δ_n [32],

$$F_{\text{nk}} = \overline{k}_n \delta_n^{\frac{3}{2}} \tag{1}$$

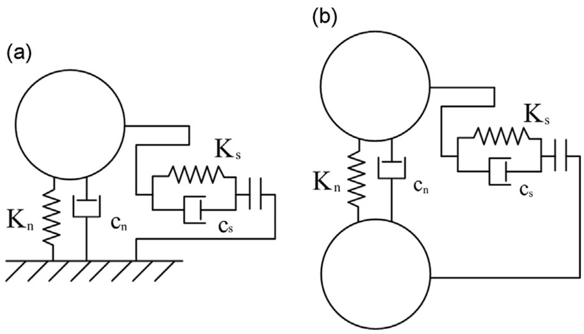

Fig. 1. Contact model for PDs. K_n: normal stiffness of contact; K_s: shear stiffness of contact; c_n: normal damping of contact; c_s: shear damping of contact.