



Rheology behavior and optimal damping effect of granular particles in a non-obstructive particle damper

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ARTICLE INFO

Article history:

Received 1 August 2015

Received in revised form

18 October 2015

Accepted 4 November 2015

Available online 3 December 2015

Keywords:

optimal damping,

NOPDs,

rheological properties of particles,

energy dissipation,

granular Leidenfrost effect

ABSTRACT

To explore the optimal damping mechanism of non-obstructive particle dampers (NOPDs), research on the relationship between the damping performance of NOPDs and the motion mode of damping particles in NOPDs was carried out based on the rheological properties of vibrated granular particles. Firstly, the damping performance of NOPDs under different excitation intensity and gap clearance was investigated via cantilever system experiments, and an approximate evaluation of the effective mass and effective damping of NOPDs was performed by fitting the experimental data to an equivalent single-degree-of-freedom (SDOF) system with no damping particles. Then the phase diagrams which could show the motion mode of damping particles under different excitation intensity and gap clearance were obtained via a series of vibration table tests. Moreover, the dissipation characteristic of damping particles was explored by the discrete element method (DEM). The study results indicate that when NOPDs play the optimal damping effect the granular Leidenfrost effect whereby the entire particle bed in NOPDs is levitated above the vibrating base by a layer of highly energetic particles is observed. Finally, the damping characteristics of NOPDs was explained by collisions and frictions between particle–particle and particle–wall based on the rheology behavior of damping particles and a new dissipation mechanism was first proposed for the optimal damping performance of NOPDs.

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1. Introduction

The non-obstructive particle damping technology, which was developed from impact damping technology, is a relatively new passive vibration damping approach. A non-obstructive particle damper (NOPD) composed of a cavity partially filled with metal or ceramic particles of small size ($\sim 0.05\text{--}5$ mm in diameter) is a device that can attenuate mechanical vibrations through inelastic collisions and frictions between the individual particles and between the particles and the cavity walls [1–3]. NOPDs are often attached to or within the vibrated structure and have been widely used in engineering practices because of their conceptual simplicity, potential effectiveness over broad frequency ranges as well as temperature and degradation insensitivity [4,5]. However, the dynamic characteristics of NOPDs is highly nonlinear and there is not an unified and mature theory about NOPDs' damping mechanism to date due to the fact that damping particles filled in NOPDs can show different motion modes (solid-like phase or liquid-like phase or gas-like phase) and even phase transitions (rheological behavior of

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particles) under certain conditions of vibration [6]. The optimal damping mechanism of NOPDs has not yet been well understood because damping particles under different motion mode show different dissipation capacity [7].

Vibrated granular beds have received much attention in both engineering and science communities over many years because they are a simple example of dissipative non-equilibrium systems that demonstrate rich and complex dynamical behaviors, such as formation of heaps [8,9], undulations and other wave patterns [10–12], arching [13], bouncing bed [14], convection [15,16], granular Leidenfrost effect [17–22] and granular gas [23,24]. NOPDs look like closed containers partially filled with damping particles. The motion mode of damping particles in NOPDs could be different from that of granular particles in a vibrated granular bed.

The novelty of this research is that the damping mechanism of NOPDs is explored first based on the rheological properties of damping particles in NOPDs and the motion mode of damping particles playing the optimal damping effect is determined. In detail, Section 2 studies the effective mass and effective damping of NOPDs under different initial conditions via cantilever system experiments and an equivalent single-degree-of-freedom (SDOF) model. In Section 3, the phase diagrams of damping particles under different excitation intensity and gap clearance are obtained via vibration table tests, by which the motion mode of damping particles playing the optimal damping effect is determined. Section 4 analyzes the dissipative properties of damping particles by DEM simulation. In Section 5, the optimal damping mechanism of NOPDs is analyzed based on the energy dissipation and transformation of granular Leidenfrost effect. Finally, conclusions are summarized in Section 6.

2. Dynamics characteristics of NOPDs

2.1. Cantilever system experiments

Forced excitation experiments of a cantilever system treated with damping particle were conducted, force and acceleration signals of the excitation point were measured with an impedance head, and then the acceleration frequency response functions (FRFs) of the system under different initial conditions were obtained via the m+p analyzer system (which is a professional dynamics testing and analysis platform for vibration and noise test, data analysis and report creation) through 32 times average for each excitation. The experiment process is illustrated in Fig. 1.

The primary system (i.e., the cantilever system) was comprised of the cantilever beam and enclosure of the NOPD together, the equivalent mass of the primary system being 0.406 kg. The experimental apparatus used in this study is shown in Fig. 2 and the component of the enclosure (which was 20 mm in inner diameter) is shown in Fig. 3. The enclosure was constructed primarily of Perspex with a carbon steel screw-bottom that allows the enclosure to be attached to the end of the cantilever beam without damage. In addition, the enclosure had a transparent Perspex sidewall that allowed the motion of damping particles to be seen, a threaded top that allowed the adjustment of the gap clearance and two threaded securing rings that prevented the gap clearance from changing during testing. The gap clearance was simply the distance between the top of the particle bed and the ceiling of the enclosure. The enclosure was filled partly with 3 mm diameter steel spheres, the mass of steel spheres being 0.063 kg. To inspect the damping performance of damping particles more clearly, only the first order modal of the primary system was analyzed in the experiments where two different cases were implemented: (1) constant gap clearance, varying excitation intensity; (2) constant excitation intensity, varying gap clearance.

First of all, let the gap clearance $L = 15$ mm (whereby the height of inner cavity of the enclosure was 60 mm), a group of sine sweep excitations were applied to the primary system treated with damping particles from 0 Hz to 50 Hz with a step rate of 25 Hz/min. The excitation intensity $\Gamma = A\omega^2/g$ (which was the dimensionless acceleration) from 0.6 to 7.8 was

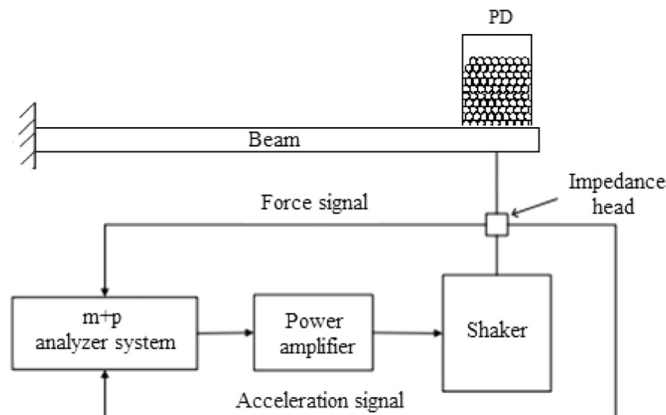


Fig. 1. Schematic diagram of experiment process.

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