

Research Article

Performance of a New Fine Particle Impact Damper

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The energy dissipation mechanisms of conventional impact damper (CID) are mainly momentum exchange and friction. During the impact process, a lot of vibration energy cannot be exhausted but reverberated among the vibration partners. Besides, the CID may produce the additional vibration to the system or even amplify the response in the low-frequency vibration. To overcome these shortcomings, this paper proposes a new fine particle impact damper (FPID) which for the first time introduces the fine particle plastic deformation as an irreversible energy sink. Then, the experiments of the cantilevered beam with the CID and that with the FPID are, respectively, carried out to investigate the behavior of FPID. The experimental results indicate that the FPID has a better performance in vibration damping than in the CID and the FPID works well in control of the vibration with frequency lower than 50 Hz, which is absent to the non-obstructive particle damper. Thus, the FPID has a bright and significant application future because most of the mechanical vibration falls in the range of low frequency.

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1. INTRODUCTION

Impact damping technology has been developed and widely used for decades in manufacture of machine tool, robot, turbo machine, airplane, rocket launcher, and so forth. At present, representative conventional impact damper (CID) includes single unit impact damper [1–5], multiunit impact damper [6–8], bean bag impact damper [9, 10], and non-obstructive particle damper [11, 12]. Any one of CID features momentum exchange or friction, where momentum exchange cannot exhaust vibration energy but reverberates it among impact partners [1–5], and friction is only good at the high-frequency vibration but bad or even magnifying at the low-frequency vibration [12].

It is well known that plastic deformation can exhaust energy as an irreversible energy sink. Many efforts have been made to use plastic deformation to absorb shock and vibration energy such as civil engineers utilize plastic deformation of minor structures to absorb earthquake energy, so that the damage could be limited, and the major structure may be kept safe [13]; ship engineers utilize plastic deformation of ship bow to absorb collision energy between ship and pier, so that both the ship and the pier could be prevented from damage [14]; automobile technicians utilize plastic

deformation of bumpers to absorb energy from collisions, so that the losses in the accidents could be alleviated [15].

Wang [16] found that plastic deformation as an irreversible energy sink is prone to occur in the plastic or fine particles, especially under the circumstance of violent vibration. Based on these findings, in this paper, we propose a new fine particle impact damper (FPID) which for the first time introduces the plastic deformation in fine particles to vibration system as perpetual energy dissipation.

2. STRUCTURE AND MECHANISM OF FPID

Fine particles are enrolled as damping agents among the impact partners (larger balls as usual) in FPID, as shown in Figure 1. Because the surface attraction of fine particles is greater than its gravity [17], the whole surface of impact partners is surrounded and affixed by the fine particles. The FPID, in which the plastic deformation of fine particles due to collisions of impact partners exhausts most of the vibration energy, for the first time introduces the plastic deformation of fine particles as perpetual energy dissipation and overcomes the shortcomings of momentum exchange and friction. Thus, it is necessary to investigate the performance of FPID by experiments.

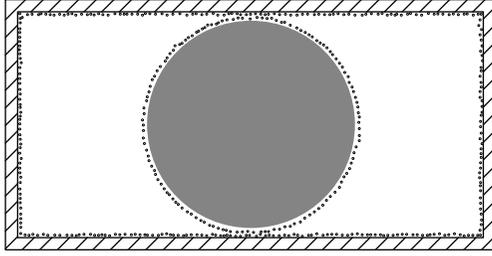


FIGURE 1: Structure of FPID.

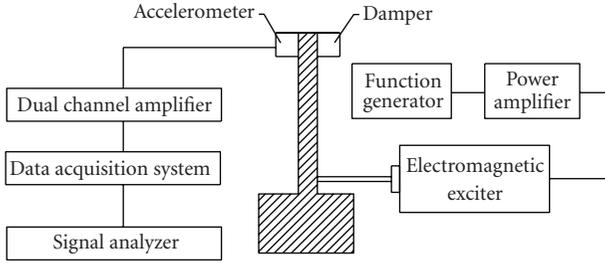


FIGURE 2: Schematic diagram of experimental setup.

3. EXPERIMENTAL DESCRIPTIONS

We use a damped cantilevered beam as depicted in Figure 2 in these experiments. The cantilevered beam made of steel is 315 mm in length, 45 mm in width, and 2.1 mm in thickness. The damper container is fixed near the tip of cantilevered beam, where the largest displacement is obtained at the first flexural mode of 12.9 Hz. The damper container is in the shape of column with 12 mm in diameter and 20 mm in height, also made of steel. In the damper container, a 10 mm in diameter steel ball with 4.1 g mass and a small quantity of copper particles with 100 μm in diameter are filled. The accelerometer placed on the back of the damper measures the tip displacement of the beam which is excited near the root through a stinger attached to an electromagnetic exciter.

To investigate the performance of FPID, experiments are, respectively, carried out on the undamped beam, on the beam damped by particle impact damper, on the beam damped by single unit impact damper, and on the beam damped by FPID. The contents of damper cavity in above four cases are listed in Table 1. In these four cases, the tip displacement of cantilevered beam at free vibration and that for the first flexible mode at harmonic excitation are measured to study the performance of FPID.

In the FPID, the damper cavity is filled with the fine particles and a steel ball with 10 mm in diameter. As shown in Figure 1, assume that the damper cavity has a total volume of V_c , the steel ball has a volume of V_b , and the filled fine particles have a volume of V_p . Thus, we define the fine particles volumetric packing ratio r_p in the FPID as

$$r_p = \frac{V_p}{V_c - V_b}. \quad (1)$$

To test the effect of quantity of filled fine particles on the performance of FPID, the tip displacements of cantilevered

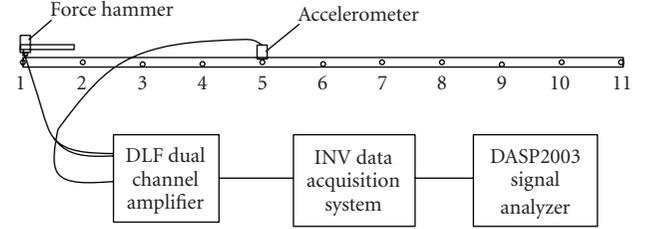


FIGURE 3: Schematic diagram of experimental scheme for mode analysis.

beam, damped by the FPID with different volumetric packing ratio r_p of 100 μm in diameter copper particles, are measured at harmonic excitation. For the filled 100 μm in diameter copper particles in the FPID designed in this paper, the relation between volumetric packing ratio r_p and mass m is listed in Table 2.

The experiments of cantilevered beam, damped by the FPID with $r_p = 20\%$ of 100 μm in diameter copper particles and that with $r_p = 20\%$ of 400 μm in diameter zinc particles, are performed at harmonic excitation to indicate the effect of different mental particles.

4. MODE ANALYSIS ON CANTILEVERED BEAM

The mode analysis on the undamped cantilevered beam adopts the signal analysis system manufactured by the China Orient Institute of Noise and Vibration. The cantilevered beam tested is equally divided into ten parts, and an accelerometer is placed on the fifth point to measure the response. A force hammer knocks each point five times and for each knocking, the force signal from the force hammer and the acceleration signal measured on the fifth point are collected by the data acquisition system. The mode analysis based on these signals is performed with the signal analysis software. The experimental scheme for the mode analysis is shown in Figure 3.

The obtained top five flexural modes of cantilevered beam are shown in Figure 4.

5. EXPERIMENTAL RESULTS

Figure 5 shows the experimental results under free vibration with the same initial displacement from the four cases listed in Table 1. The particle impact damper including 4.6 g copper particles in the cavity has only a little effect on the reduction of the tip displacement of cantilevered beam; the single unit impact damper even magnifies the tip displacement for the violet collision between steel and cavity; the FPID of $r_p = 20\%$ of copper particles has a good performance in the rapid attenuation of the tip displacement.

Figure 6 shows the experimental results under the same harmonic excitation from the four cases listed in Table 1. The particle impact damper only including 4.6 g copper particles in the cavity makes the tip displacement of cantilevered beam reduce approximately 20% for the first flexural mode; the single unit impact damper has the similar performance

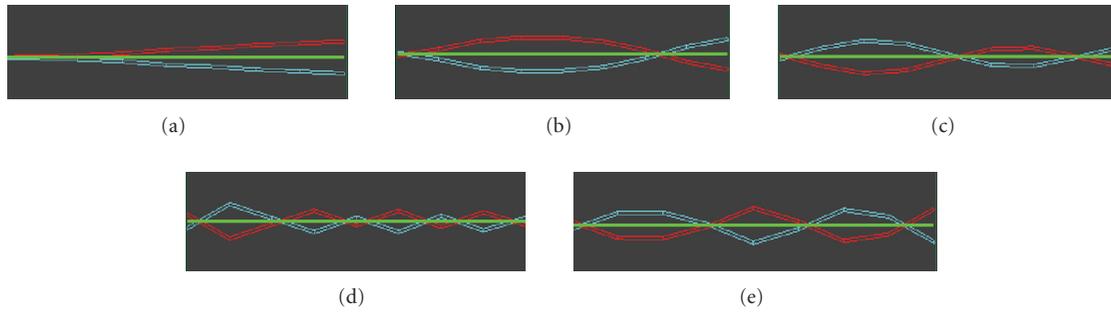


FIGURE 4: Schematic diagram of the top five flexural modes of cantilevered beam (a) the first flexural mode (13.183 Hz), (b) the second flexural mode (89.889 Hz), (c) the third flexural mode (262.667 Hz), (d) the fourth flexural mode (448.979 Hz), (e) the fifth flexural mode (524.518 Hz).

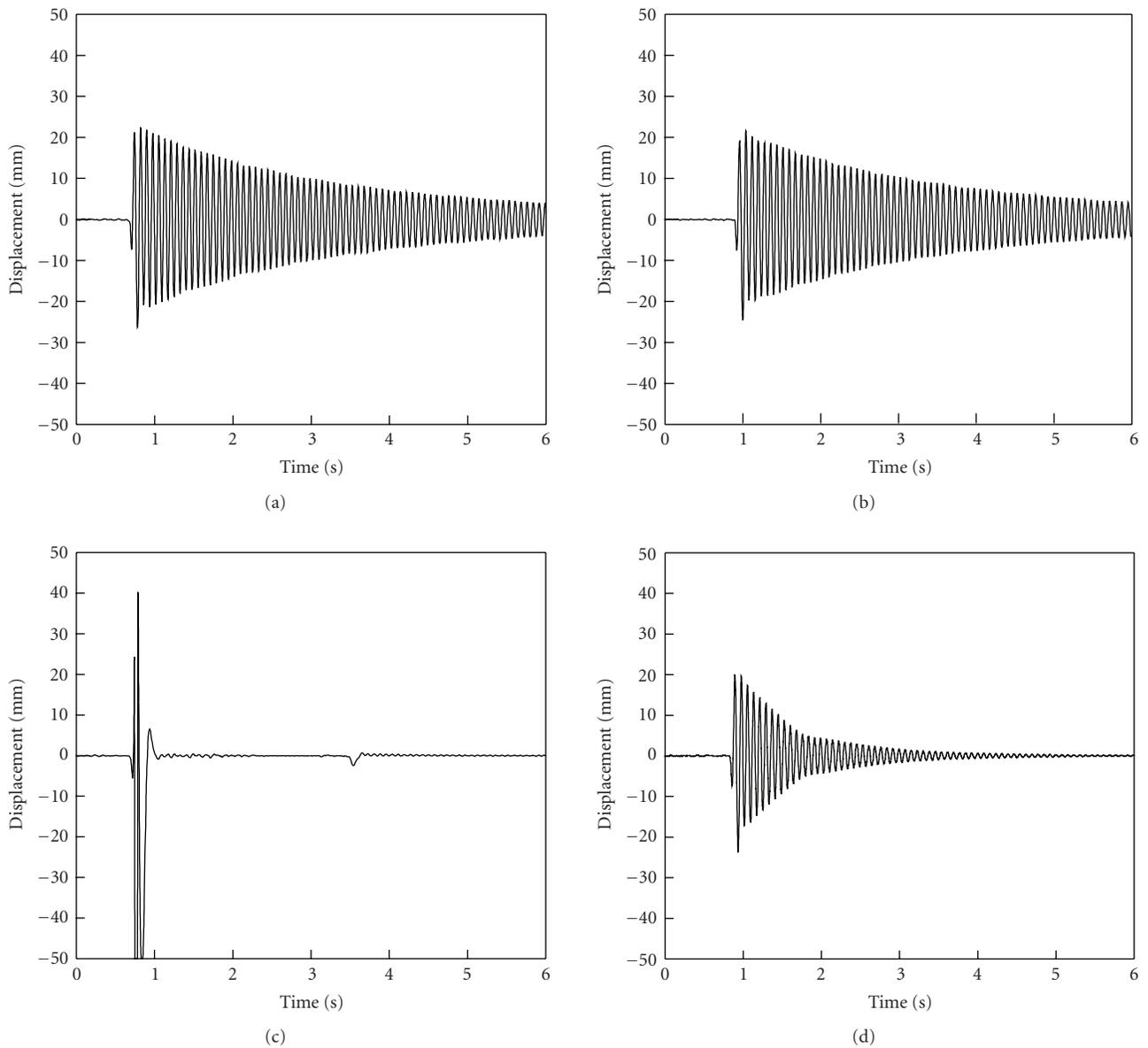


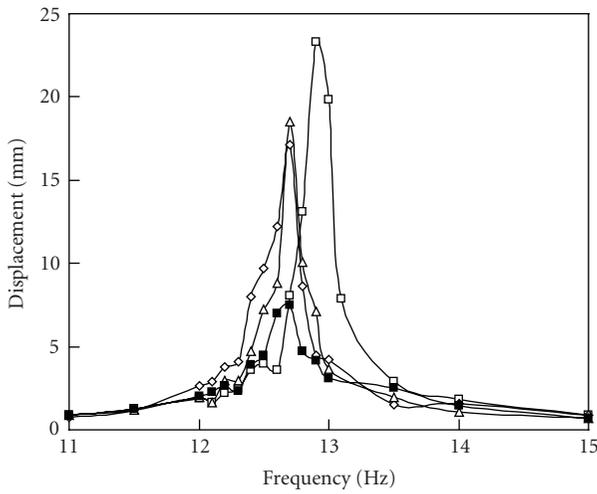
FIGURE 5: Tip displacement histories of the cantilevered beam with (a) no damper, (b) particle impact damper, (c) single unit impact damper and (d) FPID with $r_p = 20\%$ of copper particles, at free vibration of the same initial displacement.

TABLE 1: Contents in damper cavity.

Case	Damper type	Steel ball in damper cavity	Copper particles in damper cavity
(1)	No damper	None	None
(2)	Particle impact damper	None	100 μm in diameter, 4.6 g mass
(3)	Single unit impact damper	Single, 10 mm in diameter, 4.1 g mass	None
(4)	FPID	Single, 10 mm in diameter, 4.1 g mass	100 μm in diameter, 0.5 g mass

TABLE 2: Relation between volumetric packing ratio r_p and mass m for the filled copper particles in the FPID.

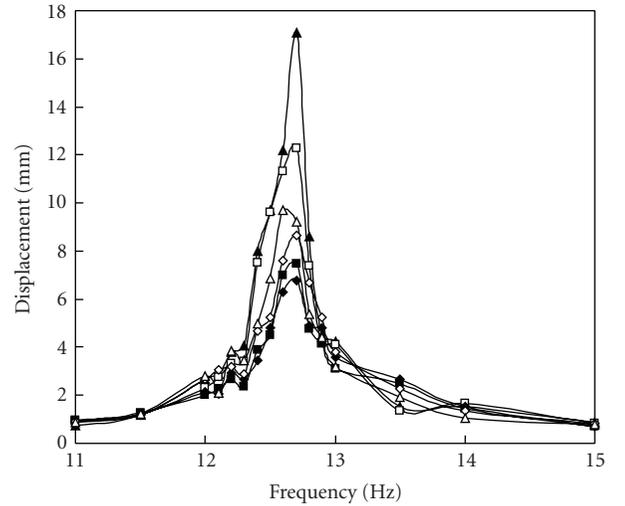
Volumetric packing ratio r_p	10%	20%	40%	60%	80%	100%
Mass m (g)	0.25 g	0.5 g	1.0 g	1.5 g	2.0 g	2.5 g

FIGURE 6: Tip displacement of the cantilevered beam with no damper (\square), particle impact damper (\triangle), single unit impact damper (\diamond) and FPID with $r_p = 20\%$ of copper particles (\blacksquare), at the same harmonic excitation.

as the particle impact damper; the FPID of $r_p = 20\%$ of copper particles is good at damping, which makes the tip displacement of cantilevered beam reduce over 65% for the first flexural mode.

These results show that the FPID has significant ability to absorb vibration energy and works well in low frequency (lower than 50 Hz). Because the auxiliary masses are kept same in the last three cases (particle impact damper, single unit impact damper, and FPID with $r_p = 20\%$ of copper particles), the excellent performance of FPID can be only attributed to the plastic deformation occurred in the fine particles.

Figure 7 is the experimental results from the FPID with different volumetric packing ratio r_p of 100 μm in diameter copper particles at the same harmonic excitation. The FPID of $r_p = 20\%$ and that of $r_p = 40\%$ work better than others, that is, too little or too much volumetric packing ratio r_p has bad effect on the performance of FPID. No matter how much copper particles are, the FPID has better damping ability than the single unit impact damper.

FIGURE 7: Tip displacement of the cantilevered beam with single unit impact damper (\blacktriangle), FPID with $r_p = 10\%$ of copper particles (\square), FPID with $r_p = 20\%$ of copper particles (\blacksquare), FPID with $r_p = 40\%$ of copper particles (\blacklozenge), FPID with $r_p = 60\%$ of copper particles (\diamond) and FPID with $r_p = 80\%$ of copper particles (\triangle), at the same harmonic excitation.

The results show that there exists an optimal packing ratio of particles in FPID, which is similar to the particle impact damping. When the packing ratio is too large, the impact partner does not have enough space to be excited, which limits the plastic deformation occurred in fine particles. While when the packing ratio is too little, the impact partner is not coated sufficiently, and thus the FPID behaves more like a single unit impact damper.

The FPID of $r_p = 20\%$ of 100 μm in diameter copper particles and that of $r_p = 20\%$ of 400 μm in diameter zinc particles are compared at the same harmonic excitation, as shown in Figure 8. The FPID of $r_p = 20\%$ of 100 μm in diameter copper particles is only a little better than that of $r_p = 20\%$ of 400 μm in diameter zinc particles, especially at the the first resonant point. It seems that both the material and the geometrical sizes of the fine particles (especially metal particles) do not alter the performance of FPID. While the samples used in this paper are still very limited, thus the

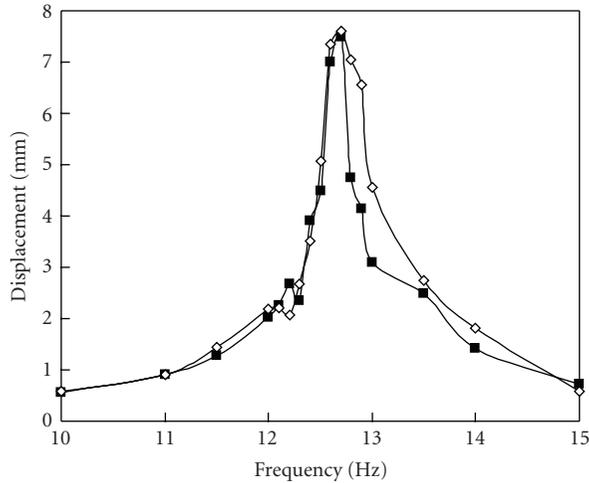


FIGURE 8: Tip displacement of the cantilevered beam with FPID with $r_p = 20\%$ of copper particles (■) and FPID with $r_p = 20\%$ of zinc particles (◇), at the same harmonic excitation.

effect of different material and size scale of fine particles on the performance of FPID deserves further research.

6. CONCLUSIONS

This paper proposes the FPID which introduces the fine particles plastic deformation as an irreversible energy sink. From the experiments of the cantilevered beam damped by the FPID and that by the CID, we draw the conclusions as follows.

- (1) The FPID has a better performance than the CID in the rapid attenuation of the tip displacement of cantilevered beam at the free vibration.
- (2) The FPID can make the tip displacement of cantilevered beam reduces over 65% for the first flexural mode at the harmonic excitation, which is much more excellent than that of the CID.
- (3) There exists an optimal volumetric packing ratio to achieve the better performance of FPID; no matter how much particles are, the FPID has better damping ability than the single unit impact damper.
- (4) The mental particles of the same volumetric packing ratio have only a little influence on the performance of FPID at the harmonic excitation, and the effect of different material and size scale of fine particles on the performance of FPID deserves further research.
- (5) The FPID works well in the frequency lower than 50 Hz, which is absent in the non-obstructive particle damper.

In spite of so many conclusions are drawn from this paper, the study has not compared the performance of proposed version to an equivalent conventional impact damper having a lower coefficient of restitution to see if the plastic deformations of the fine particles cause a

significantly different response than a single particle with equivalent plastic deformations because the lower coefficient of restitution usually would not happen in the conventional impact damper.

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