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Damping Enhancement in Structures with Particle Damper

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ABSTRACT

Passive damping techniques are useful at resonances to improve the damping and are limited to tuned resonance frequencies. A new damping technique called particle damping technique is introduced by researchers to enhance the existing damping of the structures. A particle damper is designed and developed for the application in aerospace vehicles and experiments are carried out for its characterization. Since the damping enhancement is required over a wide frequency range, random vibration tests are performed on two different structures. It has been observed that with the use of particle damper on the structure, it is able to achieve attenuation of 30%. Moreover, the particle damper is also effective for wide frequency range and with the increase in the input levels, the amount of attenuation is also increasing.

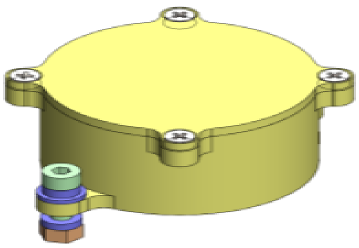
Keywords:—*Vibration suppression, random vibration, damping, particle damper.*

I. INTRODUCTION

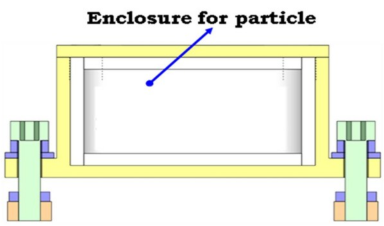
Flexible structures exhibit severe vibration and acoustic levels when subjected to excitations at resonances. Many researchers have attempted to attenuate the amplitudes by methods of passive and/or active vibration controllers. The conventional passive vibration techniques are only useful at resonances and the performance deteriorates when they need to operate beyond the excitation frequencies. Particle damping technique [1-7] is a nonlinear damping method used to enhance the structural damping of the structure and is effective in wide frequency range and suitable for harsh environments. This paper discusses only about the experimental results obtained on a flexible structures with particle damper.

II. TEST CONFIGURATIONS

An enclosure cup is designed as shown in Figure 1 to fill the particle and the damper is placed on two different structures (a beam and a plate). It consists of a bottom cup to house the particles and a lid is placed on it to cover the damper. Ratio of maximum diameter of the damper to internal diameter is 1.75. Ratio of the overall height of the damper with available height inside the enclosure is 1.57. The particle damper is developed from AA2014 material. Two 4.5 mm dia holes are provided on the damper in order to fasten it to the structure. Commercially available steel balls of diameter 3 mm, 4 mm and 6.3 mm are placed inside the cavity of the particle damper as shown in figure 2(a). In addition to this, damping enhancement studies are also carried out with sand, plastic balls and iron scrap placed inside the cavity of the particle damper as depicted in figure 2(b). The volume of the cavity is calculated and the percentage of the volume is filled with the particles to estimate the damping achieved.



1(a): Enclosure



1(b): Cross-sectional view

Figure 1: Particle damper

Particle damping studies are carried out on a flexible aluminum beam (Length = 547 mm, Width = 30.5 mm, Thick = 5 mm) clamped at both the ends as shown in Figure 3(a). Damper is placed at the center of the beam. A known acceleration spectrum is controlled at base of the beam & measured at the center of the beam. Beam with empty damper is taken as reference to estimate the damping enhancement achieved. Similar tests are conducted on the plate as shown in Figure 3(b) to find out the damping improvement.

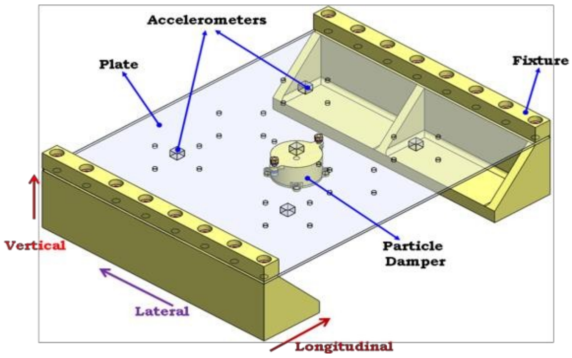
Small balls (3 mm dia) | *Medium balls (4 mm dia)* | *Big balls (6.3 mm dia)*

2(a)

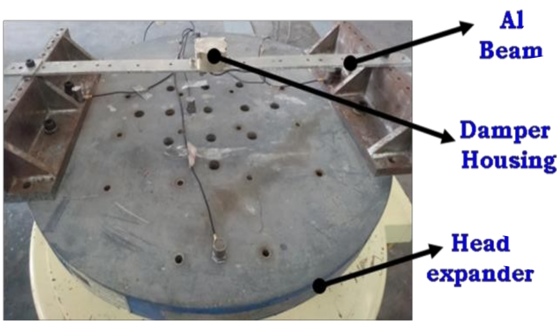
Sand | *Plastic balls* | *Iron Scrap*

2(b)

Figure 2: Different Particle Materials



3(a) Beam with Particle damper



3(b) Plate with particle damper

Figure 3: Particle damper placed on beam and plate

III. Results and Discussion

The beam clamped at both the ends is fastened to the test fixture and the test fixture in turn is fastened to the head expander of the vibration table. The beam is excited for a known acceleration spectrum from 20 Hz to 2000 Hz with two input acceleration levels of 4 g_{rms} and 8 g_{rms}. Tests are carried out with bare beam, an empty particle damper and particle damper with 40 percent volume filled with particles. An accelerometer is placed at the center of the beam and a power spectral density (PSD) is calculated for the measured response.

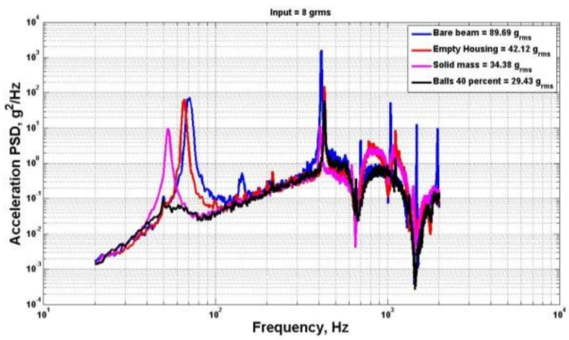
3.1. Experiments with Beams

From Figure 4(a), it has been observed that an amplification of 12.5 times is obtained in bare beam (blue curve) and when the empty particle damper is placed on the beam, the amplification is reduced to 5 times the input (red curve). In order to study the effectiveness of the particle damper, a solid mass equivalent to the mass of the particles placed in the cavity and a PSD (magenta curve) is obtained and the amplification is reduced to 4.5 times the input. When the cavity of the particle damper is filled with small balls upto 40% of its volume, then the attenuation obtained is 3.4 times the input (black curve. As depicted in the Figure, the attenuation obtained is in the wide frequency range.

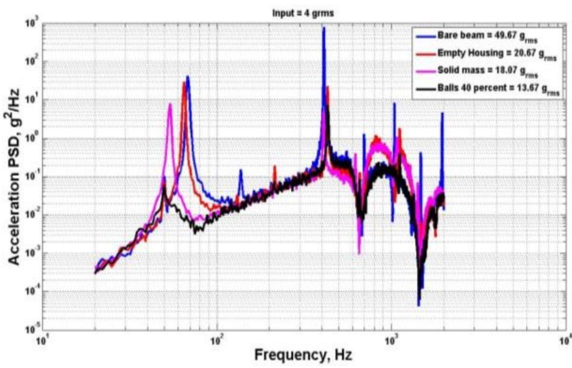
The first natural frequency of the beam is measured at 67 Hz and due to the mass effect of the particle it is reduced to 50 Hz. Even though, there is reduction in the frequency, hardly any damping enhancement is observed in the first three curves (i. e. blue, red and magenta). However, the damping is enhanced with the introduction of the particle in the cavity of the particle damper. Tests are also carried out with 8 g_{rms} input in order to study the behavior of the particle damping with increase in the input level. Similar observations are obtained with the increase in the input acceleration levels. Table 1 shows the comparison of the output acceleration levels and percentage reduction obtained with the introduction of the particle damper.

Table 1: Output acceleration (g_{rms}) level measured on the beam

Configuration	Input = 4 grms	% reduc-tion	Input = 8 grms	% reduc-tion
Bare beam	49.67	-	89.69	-
Beam with empty particle damping	20.67	58.3	42.12	53.2
Beam with solid mass	18.07	63.2	34.38	61.7
Beam with 40% small balls	13.67	72.4	29.43	67.2



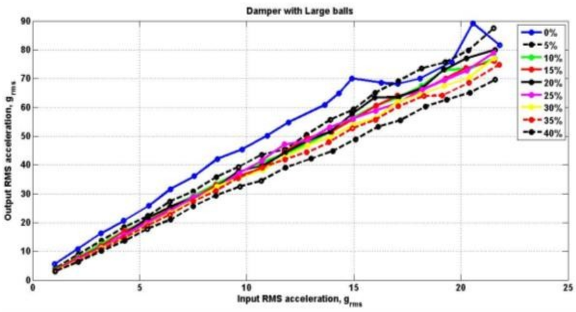
4(a) Input = 4 g_{rms}



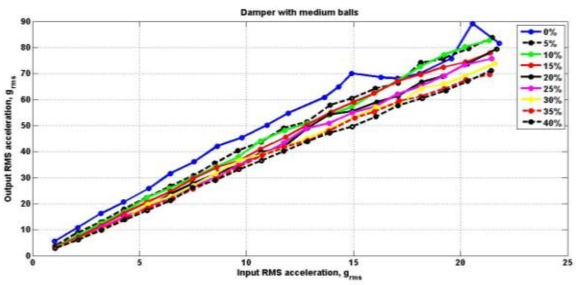
4(b) Input = 8 g_{rms}

Figure 4: Variation of power spectral density measured on the beam with particle damper for different inputs

The effect of volume fraction and the size of the particles on output acceleration obtained is shown in figure 5(a). The input acceleration is varied from 1 g_{rms} to 22 g_{rms} for frequency range from 20 Hz to 2000 Hz and the volume fraction is varied from 5% to 40%. The variation of the output acceleration (g_{rms}) with input acceleration (grms) for different volume fraction of the large dia (6.3 mm dia) particles is shown in Figure 5(b). Figure 6 shows the variation of the output acceleration levels for different size of the particles with constant volume fraction of 40%. It has been observed that as the volume fraction of balls in cavity of the particle damper is increasing, there is a reduction in output RMS. Moreover, as input excitation is increasing, amount of attenuation also increases.



(a) Steel ball 4 mm dia



(b) Steel ball 6.3 mm dia

Figure 5: Variation of output acceleration (g_{rms}) measured on beam with input acceleration for different volume fraction of particle

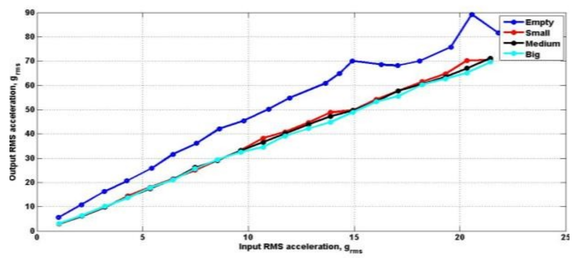


Figure 6: Variation of output acceleration (g_{rms}) with input acceleration for 40% volume fraction of different dia particles

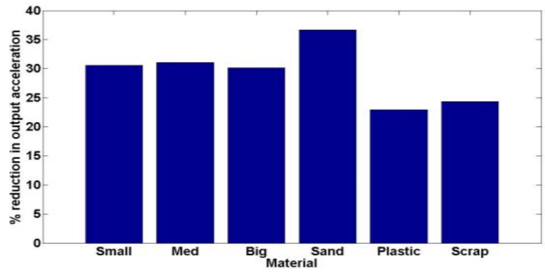


Figure 7: Percentage reduction in the output acceleration of the beam for different particles placed in the cavity of particle damper (40 % volume fraction)

It has been observed from figure 7 that the metal particles inside the cavity of the particle are able to attenuate the output acceleration levels upto 30% whereas the experiments conducted with sand is able to attenuate the acceleration levels upto 38%. With plastic balls and iron scrap, the attenuation achieved is of the order of 20% and 22% respectively.

3.2. Experiments with Plates

Particle damper is placed at the center of the plate as shown in figure 3(b) clamped at two edges and other two edges are free. Input acceleration as depicted in figure 8 is applied at the input of the plate and the output acceleration is measured to find out the power spectral density at the center of the plate. The two opposite edges of the plate is fastened to the clamping fixture and is mounted on the vibration fixture. The particle damper is placed in two directions viz. longitudinal and lateral as described in figure 9 to study the effect of orientation of the particle damper on the output acceleration of the plate.

The variation of the output acceleration power spectral densities of the plate in longitudinal and lateral orientation of the particle damper is given in figure 10(a) and Figure 10(b) respectively. The measured acceleration (g_{rms}) levels are summarized in Table 2. It has been observed that as the size of the particles are increasing, the more the attenuation and minimum 20%

attenuation in the output acceleration levels is achieved. The peak acceleration level at the first mode is also reduced by 1/10th. When the particle damper is oriented in lateral direction, the attenuation achieved is of the order of 26%. With the use of the particle damper, the contribution of the higher frequencies is reduced to the overall response calculation and hence, a wide band damping attenuation is able to demonstrate.

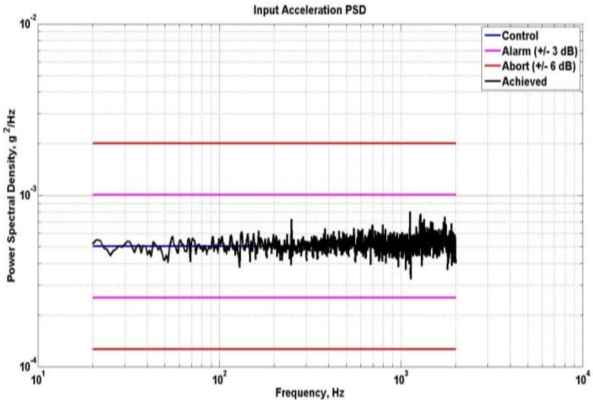
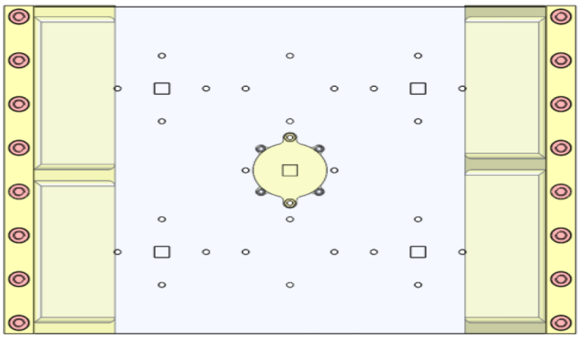
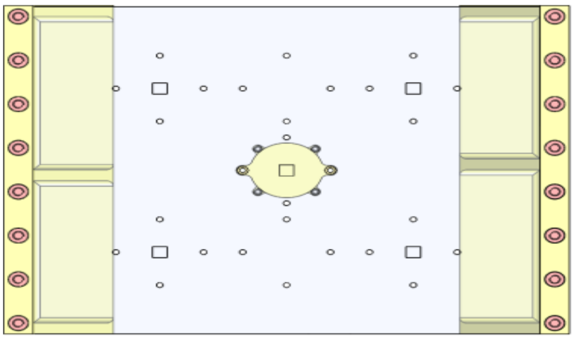


Figure 8: Input acceleration spectrum applied at the base of the clamped-clamped plate

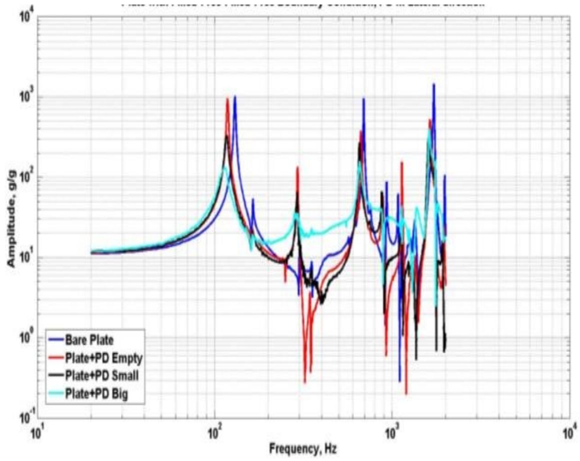


(a) Particle damper in Longitudinal direction

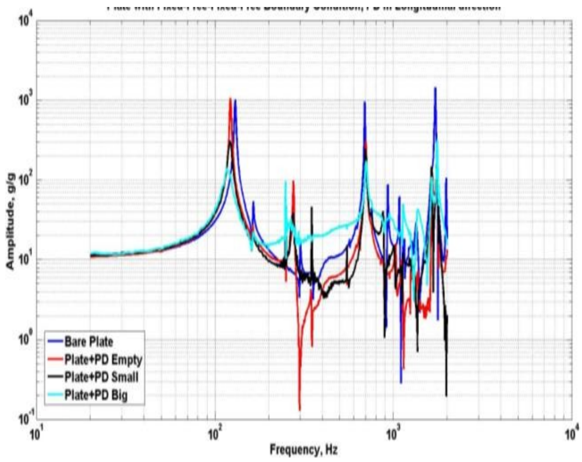


(b) Particle damper in Lateral direction

Figure 9: Orientation of Particle damper on the clamped-clamped plate



(a) Longitudinal Direction



(b) Lateral Direction

Figure 10: Comparison of the power spectral densities on the plate with particle damper in two directions

Table 2: Output Acceleration (grms) Measured on the Plate with Particle Damper (PD)

Test Configura-tion	RMS Acc (grms)	Peak Acc (g2/Hz)	
	Freq = 20 Hz to 2000 Hz	Mode 1	Mode 1
Bare Plate	141.03 Long Lat	557.2 Long	Lat
Plate + PD Empty	51.89 77.82	415.2	485.6
Plate + PD Small	41.21 57.27	44.85	57.48
Plate + PD Big	46.16 66.59	10.27	10.25

IV. CONCLUSIONS

With the use of a particle damper, a significant amount of attenuation is achieved in the output acceleration levels of the structures. Minimum of 30% reduction is able to obtain with the cavity designed for the particle damper. The size of the particle or the volume fraction plays a vital role in establishing the attenuation required. As the number of balls are increasing, there is a reduction in output RMS. As the input excitation is increasing, the amount of attenuation also increases. This technique of damping enhancement can be applied to airframes of the aerospace vehicle such that the cavities of the airframes are locally filled with particles to improve the damping. This method is helpful in achieving the wide band attenuation and is suitable for harsh thermal environments.

ACKNOWLEDGEMENTS

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