Experimental Evaluation of Effect of Various Material Parameters on the Performance of Particle Impact Damper to Reduce Vibrations

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***Abstract* - Viscoelastic damping is one of the most common method of passive damping. However, the damping properties of viscoelastic materials are strongly dependent on several parameters including strain rate, aging and temperature, pressure etc. The dependence on the external operating conditions can eliminate viscoelastic materials as a viable damping solution in certain applications, particularly where ambient operating temperatures are more severe, such as in cryogenic environments. Particle impact damping (PID) is an alternative passive damping method in which a particle filled enclosure is attached to a structure undergoing oscillatory vibration. The particles absorb kinetic energy of the structure and convert it into heat through inelastic collisions between the particles and the enclosure. In this work, PID is measured for a simply supported beam with the damping enclosure attached to it. Various parameters of the particles have been observed. Effect of Various Materials of the particles, Size of particles, quantity of particles, effect of using powders instead of particles on the performance of particle impact damper (PID) have been studied. From experimental analysis, It is observed that the performance of PID is independent on the external operating conditions such as temperature, pressure etc, but it is dependent on the various material parameters such as materials of the particles, size of particles, quantity of particles, using powders instead of particles etc. The expected reduction in vibrations by this set up is up to 20%.**

Keywords- PID, Viscoelastic damping, passive damping.

I. INTRODUCTION

The operation of any mechanical system will always produce some vibrations. Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. Vibration can be desirable - for example, the motion of a tuning fork, the reed in a woodwind instrument or harmonica, or mobile phones or the cone of a loudspeaker. In many cases, however, vibration is undesirable-wasting energy and creating unwanted sound. For example, the vibrational motions of engines, electric motors, or any mechanical device in operation are typically unwanted. Such vibrations can be caused by imbalances in the rotating parts, uneven friction, the meshing of gear teeth, etc. Careful designs usually minimize unwanted vibrations. Our goal is to minimize the vibrations, because while it is undesirable, vibration is unavoidable. The result of excess vibration can vary from nuisance disturbance to a catastrophic failure. All automobile vehicles, aerospace vehicles generate some vibration. This vibration may just be an indicator of some problem with a mechanism, or it may be a cause of other problems. When any elastic body such as spring, shaft or beam is displaced from equilibrium position by the application of external forces and then released, it commences cyclic motion. Such cyclic motion of a system due to elastic deformation under the action of external forces is known as vibration. The presence of unwanted vibrations in a structure must often be overcome to avoid damage and eventual failure due to high cycle fatigue. The reduction of these vibrations is achieved by converting the mechanical energy of the structure into thermal and acoustic energy. Damping of structural vibrations can be realized through either active or passive means, the latter being the most common. Active Dampers are vibration dampers that require external power source for their working, while passive dampers do not require any external power source for their working. Hence passive dampers are more commonly used. Viscoelastic damping is one of the most common method of passive damping. Viscoelastic damping is achieved by converting the vibrating structure’s stored elastic strain energy into it. However, the damping properties of viscoelastic materials are strongly dependent on several parameters including strain rate, aging and temperature. At extremely low and high temperatures viscoelastic material properties are characterized by glassy and flow regions, respectively. In these regimes the damping properties are distinctly diminished. The dependence on the external operating conditions can eliminate viscoelastic materials as a viable damping solution in certain applications, particularly where ambient operating temperatures are more severe, such as in cryogenic environments. Particle impact damping (PID) is an alternative passive damping method in which a particle filled enclosure is attached to a structure undergoing oscillatory vibration. A Particle Impact Damper consists of a bed of granular materials moving in cavities within a structure. Particle Impact Damping is a method to increase structural damping by inserting particles in an enclosure attached to a vibrating structure. The particles absorb kinetic energy of the structure and convert it into heat through inelastic collisions. It has many practical applications in the control of free and forced vibrations. Although the concept of PID is relatively simple there are many damping mechanisms which contribute to the dissipation of energy, resulting in highly nonlinear behaviour. As the primary system vibrates, particles within the enclosure undergo inelastic collisions among themselves and the container walls, dissipating the kinetic energy of the structure as heat.

Particle impact damping (PID) is a method to increase structural damping by inserting particles in an enclosure attached to a vibrating structure. The particles absorb kinetic energy of the structure and convert it into heat through inelastic collisions between the particles and the enclosure. The unique aspect of PID is that high damping is achieved by converting kinetic energy of the structure to heat as opposed to the more traditional methods of damping where the elastic strain energy in the structure is converted to heat.

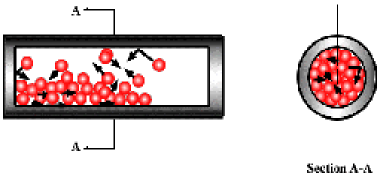


Fig 1.1: Cross-section of a Particle Impact Damper.

II. PROBLEM DEFINITION

Our goal is to minimize the vibrations, because while it is undesirable, vibration is unavoidable. The result of excess vibration can vary from nuisance disturbance to a catastrophic failure. Viscoelastic damping is one of the most common method of passive damping.. However, the damping properties of viscoelastic materials are strongly dependent on several parameters including strain rate, aging and temperature, pressure. At extremely low and high temperatures viscoelastic material properties are characterized by glassy and flow regions, respectively. In these regimes the damping properties are distinctly diminished. The dependence on the external operating conditions can eliminate viscoelastic materials as a viable damping solution in certain applications, particularly where ambient operating temperatures are more severe, such as in cryogenic environments. In short, the performance of viscoelastic damper is affected in cryogenic environment. Therefore we cannot use viscoelastic damper at very low or high temperature and pressure. This problem can be avoided by using particle impact damper (PID).

III. OBJECTIVE OF PROJECT

The objective of this project is to minimize the vibrations up to 20% and to study the effect of various material parameters on the performance of particle impact damper. Hence, our goal is to design a particle based damping system to damp the vibration of structure caused due to mechanical elements and evaluate the effect of various material parameters listed below on the performance of Particle Impact Damper.

1. Effect of various materials of the particle
2. Effect of size of the particles
3. Effect of quantity of particles
4. Effect of non metallic containers.

IV. LITERATURE REVIEW

Several studies have been conducted relating to the effectiveness of particle impact damping in attenuating undesirable vibrations.

R. D. Friend and V. K. Kinra[1] have presented an experiment where PID is measured for a cantilever aluminium beam with the damping enclosure attached to its free end; lead particles were used in that study. The effect of acceleration amplitude and clearance inside the enclosure on PID is studied. PID is found to be highly non-linear. Driven by the experimental observations, an elementary analytical model of PID is constructed. A satisfactory comparison between the theory and the experiment was observed.

In 28 April 2003, Zhiwei Xu, Michael Yu Wang[2], Tianning Chen investigated an application of particle damping technique for noise reduction of a desk-top industrial machine. Particle damping is a technique of providing damping with granular particles embedded within small holes in a vibrating structure. The particles absorb kinetic energy through particle-to-wall and particle-to-particle frictional collisions.

Steven E. Olson[5] developed an analytical particle damping model**.** According to them, Particle damping is a passive vibration control technique where multiple auxiliary masses are placed in a cavity attached to a vibrating structure. The behaviour of the particle damper is highly non-linear and energy dissipation, or damping, is derived from a combination of loss mechanisms.

Zheng Lu, Xilin Lu, Wensheng Lu & Weiming Yan[6] did an Experimental Investigation into the Use of Buffered Particle Dampers**.** They presented a systematic experimental investigation of the effects of buffered particle dampers attached to a multi-degree-of-freedom (MDOF) system under different dynamic loads (free vibration, random excitation as well as real onsite earthquake excitations). A series of shaking table tests of a three-storey steel frame with the buffered particle damper system are carried out to evaluate the performance. It is shown that buffered particle dampers have good performance in reducing the response of structures under dynamic loads, especially under random excitation case.

M. Saeki[8] has presented experimental and analytical studies of the performance of a multi-unit particle damper in a horizontally vibrating system. An analytical solution based on the discrete element method is presented. Comparison between experimental and analytical results shows that accurate estimates of the rms response of a primary system can be obtained. Multi-unit particle dampers are passive damping devices involving granular particles in some cavities of a primary system. The principle behind particle damping is the removal of vibratory energy through losses that occur during impact of granular particles.

V. METHODOLOGY

1. To study and measure the vibration characteristics of the system.
2. Determine vibration characteristic of the system with adjusted mass.
3. Preparing the experimental setup.
4. To study and measure the vibration characteristics of the demo set up with particle impact damper.
5. Evaluate the effect of various material parameters on the performance of Particle impact Damper.
6. Testing and results.
7. Preparation of report

VI. THEORETICAL ANALYSIS

According to theory developed by Friend and Kinra, The stiffness of the beam is given by,

$$k = \frac{48EI}{L^3} \qquad (6.1)$$

Let, ω be the circular frequency of the fundamental mode, and ψ_b be the intrinsic material damping of the beam material. The reduced damping coefficient of the beam is given by,

$$c = \frac{\psi_b}{2\pi}\sqrt{KM}(6.2)$$

Then, the damping ratio, $\xi = {}^{c}/_{c_{cr}} = {}^{\psi_b}/_{4\pi}$. Since the exact mode shape of the beam is used to compute M and K, the undamped natural frequency of the single degree of freedom system, $\sqrt{{}^{K}/_{M}}$ is exactly equal to the undamped natural frequency. Moreover, for the beam used in this study, the damped natural frequency maybe approximated by its undamped natural frequency.

$$\sqrt{{}^{K}/_{M}}$$

In most vibration problems the mass of the beam remains constant. Therefore, the static deflection due to the weight of the beam also remains constant and is neglected. The problem at hand is a little bit more complicated: there are times when the particles move in contact with the beam, and at other times they move separately from the beam. To keep the model simple, first it is assumed that all particles move as a lumped mass, m, i.e. the relative motion between the particles is neglected. It follows then that the end mass, me, is a two-valued function. Moreover, the static deflection due to gravity is no longer a constant. Therefore, the static deflection must be taken into account in the analysis of the problem for the derivation of the equations. With this observation, the analogy between the continuous beam and its equivalent discrete single degree of freedom system is complete.

Specific damping capacity (ψ) is defined as the kinetic energy converted into heat during one cycle (ΔT) normalized with respect to the maximum kinetic energy of the structure during thecycle (T),

$$\psi = {}^{\Delta \mathrm{T}}/_{T} \qquad (6.3)$$

Where T is given by,

$$T = {}^{1}/_{2}\, MV^2 \qquad (6.4)$$

The energy dissipated during the ith cycle is calculated using,

$$\Delta \mathrm{T}_i = T_i - T_{i+1} \qquad (6.5)$$

Since the experiment cannot determine whether or not the particles are in contact with the enclosure at any given instant, it is assumed that the particles are in contact with the enclosure at velocity peaks. Then, the mass of the particles, m, and the energy dissipated can be expressed as,

$$\Delta \mathrm{T}_i = \frac{1}{2}M(V_i^2 - V_{i+1}^2) \qquad (6.6)$$

Substituting, damping during the ithcycle is expressed as,

$$\psi_i = \frac{V_i^2 - V_{i+1}^2}{V_i^2} \qquad (6.7)$$

Friend and Kinra introduced a parameter R (effective coefficient of restitution) that is a measure of the total energy dissipated during one cycle due to all possible mechanisms of energy dissipation (for example, inelastic collisions and frictional sliding amongst the particles, and between the particles and the enclosure). Velocity of the particle and the primary mass before (after) an impact, R was defined as

$$R = \frac{(\nu_p^+ - \nu_2^+)}{(\nu_p^- - \nu_2^-)}$$

The energy dissipated during an impact is given by,

$$\Delta \mathrm{T} = \frac{1}{2}(1\ \mathrm{R}^2)\frac{\mathrm{m}}{(1+\mu)}(\nu_p^- - \nu_2^-)^2$$

Where, R is estimated by minimizing the difference between the theory and the experiment using the method of least squares. There are several parameters that affect energy dissipation during an impact,

$$\Delta T = f(m, d, g, M, \omega, U; R)$$

Where, g is the gravitational constant, o is the fundamental frequency (in rad/s) of the beam, d is the clearance (i.e. the distance between the top of the bed of particles at rest and the ceiling of the enclosure), and U is the vibration amplitude. The semicolon separating R is used to emphasize that R is obtained by curve-fitting experimental data to the model. In dimensionless parameters,

$$\psi = f(\mu, \Gamma, \Delta T, R)$$

Where $\Delta = \frac{d\omega^2}{g}$ =dimensionless clearance, and

$\Gamma = \frac{U\omega^2}{g}$ =Dimensionless amplitude.

VII. EXPEREMENTAL SET UP AND PROCEDURE

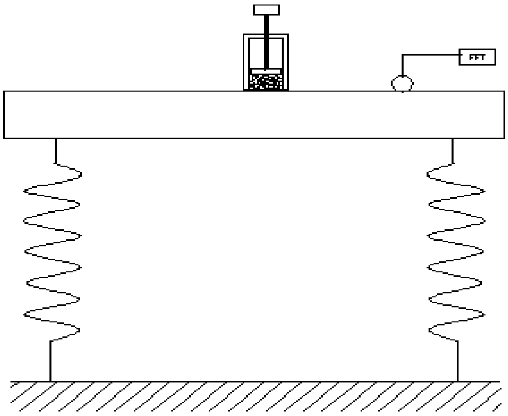


Fig 1. Experimental set up

A schematic of the test set up is shown in figure no 1. The experimental set up consists of a particle enclosure attached to a steel simply supported beam. The clearance, d, can be varied by adjusting the ceiling of the enclosure using a threaded screw. The enclosure is attached to beam by means of screw. The exciter is attached at middle of beam.

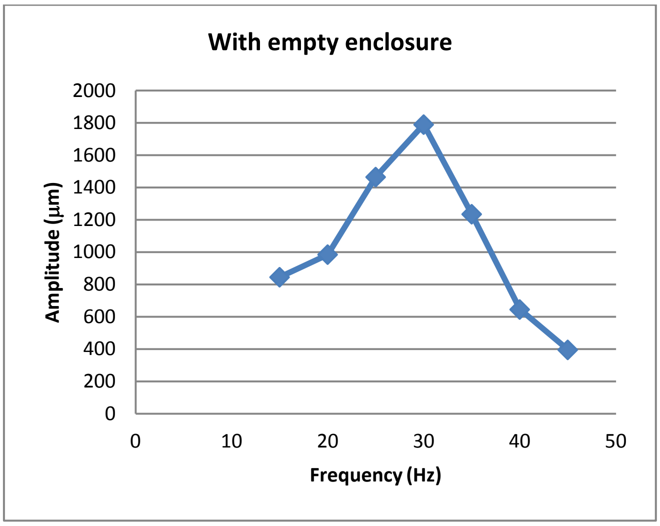
In this project seven different particle materials are tested. These particles are Lead shots, Steel balls, Glass spheres, Sand etc. Readings have been taken by using FFT analyser.

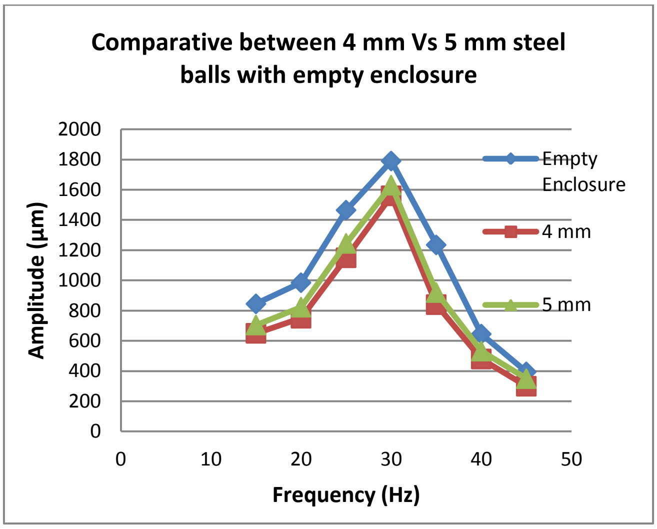
Following materials were tested.

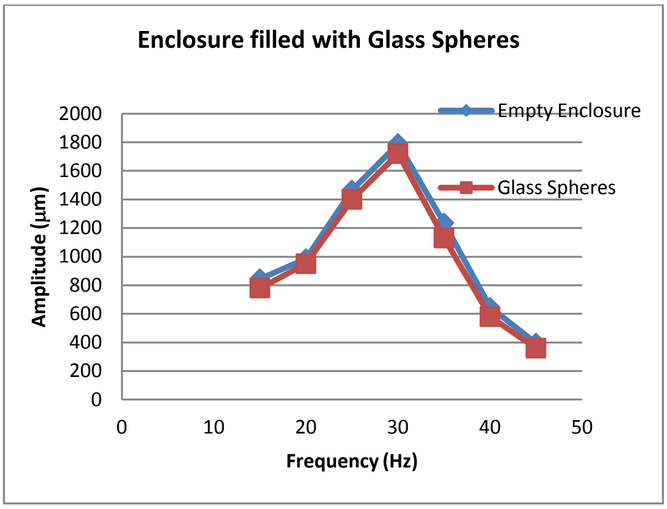
Sr. No.	Material	Density(g/cc)	Size of Particles
1	Lead	11.34	5mm
2	Steel	7.85	4 & 5mm
3	Glass	2.5	13 & 17mm
4	Sand	1.9	3mm

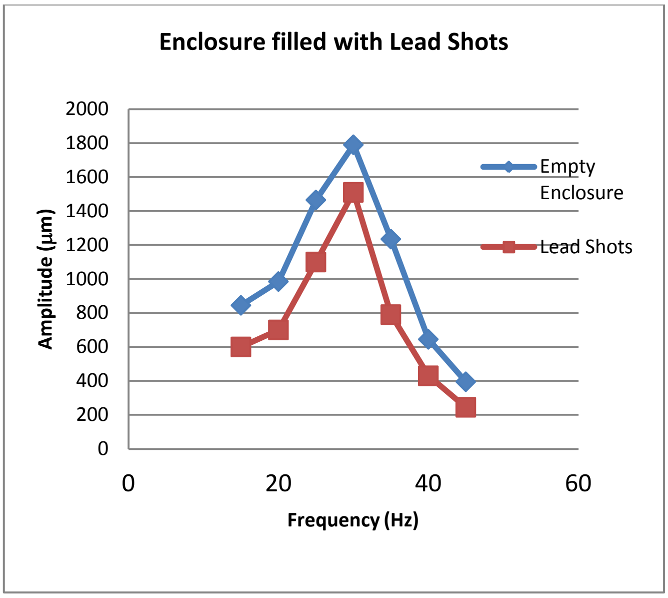
VIII. EXPEREMENTAL RESULTS

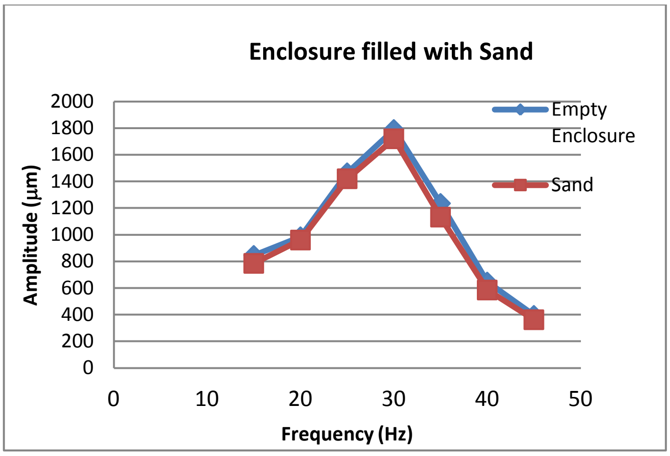
Following are the results by FFT analyser for different particle materials.

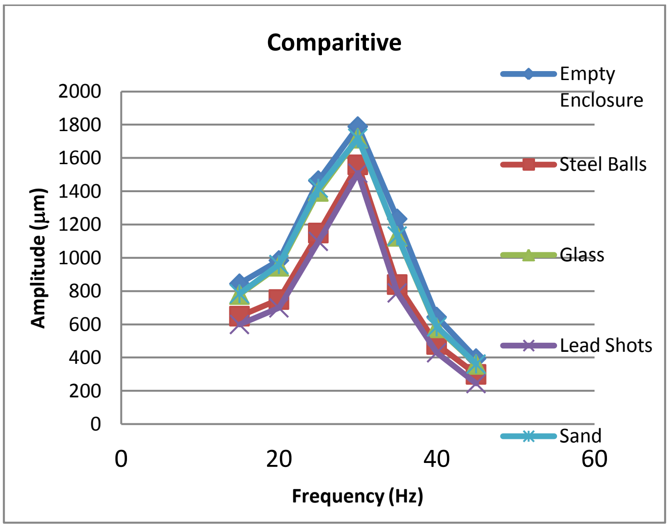












IX. CONCLUSION

In this project we conclude that damping is dependent on density of materials. Materials with higher density provide greater damping as compared to materials with lower density. This was observed by comparing damping observed due to steel balls and lead shots.

The average damping obtained by using steel balls was around 13-20 % and the average damping obtained by using glass spheres was around 3-7%. The average damping obtained by using lead shots was around 20-30 % and the average damping obtained by using sand was around 5-10%.

We also conclude that damping is dependent upon size of particles. Damping was reduced as size of particles was increased. This was observed in case of steel balls of 4 mm and 5 mm diameter. The damping observed by using 5 mm steel balls was less as compared to that obtained by using 4 mm steel balls. In case of particle impact damping it was observed that the kinetic energy lost due to inelastic collisions is converted into heat. Hence suitable heat dissipation arrangements need to be provided. However particle impact damping is effective over wide range of temperatures as compared to viscous damping.

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