PERFORMANCE EVALUATION OF PARTICLE DAMPING FOR GEAR TRANSMISSION SYSTEM

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Abstract: Gear transmission system is widely used for many mechanical applications to transfer power. Specially in case of spur gears, due to high speed and heavy loading conditions the vibrations are unavoidable. This result in reduction in service life of gear. Particle damping is one of the passive vibration damping technology. This dissertation work deals with use of particle damping technique to reduce the vibration in gear system by dissipating vibrational energy in particle collisions. Theoretical analysis of particle damping is carried out to determine the important parameters which affect its performance. Single stage spur gear system is used for project work. Static structural and modal analysis is performed using FEA tool to find stress distribution and natural frequencies at various modes. Using Taguchi method of design of experiment, total nine test runs are identified for two parameters at two different level. Suitable DEM tool is used to perform simulations at different speed and to analyse the energy dissipation during particle collisions. The effect of particle size and particle filling percentage is analysed for gear having six holes to fill particles. The results can be used as guide for applying particle damping under centrifugal load.

Keywords: Gear transmission, Particle damping, DEM (Discrete element method), FEA (finite element analysis).

I. INTRODUCTION

Vibrations are many times cannot be avoided or eliminated in most of the machinery. There can be two methods to reduce their effects; one is vibration damping and other vibration isolation. Vibration damping is the process of absorbing or changing vibration energy to reduce the amount of energy transmitted to the equipment or machinery, while vibration isolation prevents energy from entering machinery. There are mainly three methods of vibration damping as active, passive and semi-active methods. One can differentiate between active and passive methods by means by their use. Passive systems use simple mechanical devices, fluids or elastomeric materials, whereas active vibration damping relies on a closed – loop system with feedback. Particle damping has its origin in impact damping technique. Instead of using single impactor, particles are used in particle damping method. Particle damping technique is an auxiliary-mass type vibration damper, in which multiple metal particles, tungsten carbide, ceramic or other types of small particles are placed within the cavities of vibrating structure or the enclosures attached to the vibrating structure in order to reduce the response of primary structure. The damping effect is produced due to particle to particle and particle to wall inelastic collisions and frictional losses. It is non-linear type of system.

Advantages of particle dampers include Conceptual Simplicity, moderate cost, good durability, ability to sustain wide range of working temperatures, tungsten powder can withstand temperatures of nearly 2000 °C, Particle damper are also suitable in long term harsh environments, such as severe cold, oil contaminations, where other types of damping devices are no longer suitable or efficient, low maintenance damping technology. Mechanical engineering applications uses gear transmission systems for speed, torque conversions from a rotating power source to another device. Many times, due to high speed and heavy loading conditions the vibration of tooth surfaces of gear transmission increases and becomes more severe which will result into shortening the service life. So, there is need to reduce the vibration. Particle damping technique can be used to reduce vibration at source itself.

Zheng Lu. et al. [1] have done review of research work in field of particle dampers. It provides an overview of particle damping technology, starting with its basic concepts, developmental history and research status all over the world. A discrete element method of simulating a multi- degree of freedom structure with a particle damper is also illustrated. **Yanchen Du** [2] developed a spring supported fine particle impact damper to reduce harmonic vibration of cantilever beam. Here observation of the combined effects of elastic deformation and plastic deformation to attenuate the vibration of cantilever beam is done. Study of the developed damper experimentally and established a dynamic model for understanding its mechanism is carried out. The effect of chamber clearance ratio, stiffness ratios are analyzed with model. It was found that spring supported fine particle impact damper reduces 80 percentage of the maximum amplitude of cantilever beam at the resonance point which is better compared to 40 percentage of single impact damper. **Wangqiang Xiao** et al. [3] Particle damping technology widely applied for horizontal and vertical steady field and seldom used for rotary field. Investigated gears with drilled via holes filled with damping particles. DEM (Discrete element method) is used to develop energy dissipation model for particle system accounting for friction and inelastic collisions. It was observed that an unsuitable filling rate would significantly reduce damping effectiveness. **Wangqiang Xiao** et al. [4] carried out study of vibration suppression of gear transmission system using particle damping technology. Investigation of influence of particle size on energy dissipation has been done. Choosing an optimal particle diameter will help to effectively reduce the vibration of gear system for different rotational speed and loads. **C. Zhang** et al. [5] carried out performance analysis of particle damper under centrifugal load. Modeling of particle damper rotational conditions was done and investigated the effect of cavity. The cavity of particle damper was a circular hole. Discrete element method was used to simulate the particle damper. Study of the effects of orientation and aspect ratio of the particle dampers hole on the vibration reduction was carried out. Results showed that the hole of the particle damper drilled perpendicular to the centrifugal load achieved better damping effect and a slender hole i.e. length is larger than diameter, provided a better vibration reduction effect. Here aspect ratio is ratio of length of hole to diameter of hole. It was found that as rotational speed increases the optimal aspect ratio also increased. The results obtained can be used as a guide in the design of particle dampers under rotational conditions. **T.A. Jadhav and P.J. Awasare** [6] have used particle damping method to reduce the vibration of cantilever beam. Instead of using single cell enclosure, made compartments to convert it into multi-cell enclosure and enhanced the effect of damping. The single cell and multiple cell enclosures are tested keeping the mass of particle constant, which revealed that damping effectiveness is increased significantly using a multiple cell. A mathematical model has been proposed for a single cell enclosure using dimensional analysis method and this model is modified for multiple cells and it was observed that there was a good correlation between analytical and experimental results.

II. PARAMETER SELECTION AND DISCRETE ELEMENT METHOD

In case of particle damping the mechanism mainly includes the energy consumption among particles and the impact energy dissipation between particles and the main structure.

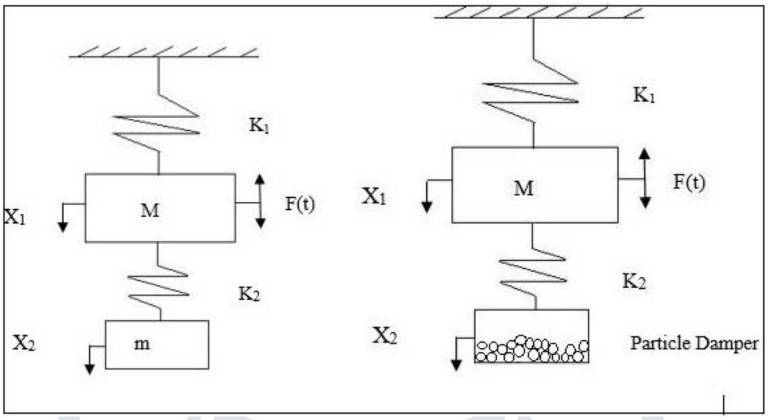

Fig. 1 Mechanical model of dynamic vibration absorber and particle damper

In above figure 1, X_1 and X_2 are displacements of primary system and absorber respectively. K_1 and K_2 are stiffness of primary system and absorber; M and m are equivalent mass of primary system and absorber; F(t) is the externally applied force. Performance of particle damping depends on important parameters like,

a) The material of the particles
b) Size of particles
c) Number of particles used
d) Number of containers
e) Aspect ratio (ratio of length to diameter of hole)
f) Particle filling percentage

Each of the above factor will influence the damping effect in one or the other way. For the proposed work size of particles, particle filling percentage, number of particles and number of containers are selected as parameters which affect the damping of vibrations. The parameters selected can be varied at different level to observe its effect on energy dissipation.

Discrete element method is widely used to do analysis of particle dampers. It is an effective method to solve the non-continuum problems. As this method account for particle-particle and particle wall interactions, it is quite suitable to analyse particle dampers quantitatively. The discrete element method has three parts. At start of the process divide the object of focus into small independent units, then based on interaction between particles units and Newton's second law, the displacement of all particle units at each time can be calculated using dynamic or static relaxation iteration method. Lastly update the position of all particle units. After tracking and calculating the micro-motion of each particle unit, the macroscopic motion of the whole system can be obtained. The important assumption of DEM is the velocity and acceleration are constant during any time step.

III. DESIGN OF EXPERIMENTS (TEST RUNS) FOR SIMULATIONS

Taguchi Method is used for designing of experimental tests. Considering the radius of steel balls and particle filling percentage as two parameters, which can be varied at three different levels. The following table 1 shows the parameters and their levels. For above two parameters and three levels, according to Taguchi method nine tests need to be carried out.

Table 1 Parameters and their levels

Parameters	Level 1	Level 2	Level3
Radius of steel balls(mm)	1	2	3
Particle filling Percentage	<50	50	>50

After assigning parameter values to Taguchi array, following nine tests need to be simulated to obtain effect of radius and particle filling percentage on vibration reduction.

Table 2 simulation test runs for parameters at different level

Test Run	Parameter A	Parameter B	
	Radius of steel ball (mm)	Particle filling in Percentage	Speed in rpm
1	1	<50	300
2	1	50	500
3	1	>50	800
4	2	<50	300
5	2	50	500
6	2	>50	800
7	3	<50	300
8	3	50	500
9	3	>50	800

IV. DEM SIMULATIONS

The discrete element method precisely includes discrete approach which has abilities to numerically calculate finite particle displacements and rotations and to automatically perform contact detection for an assembly of particles. Using contact detection algorithms and suitable contact models, DEM simulations are capable of calculating forces acting on particles. Accelerations, velocities and positions are then computed using Newton's laws of motion and numerical integration.

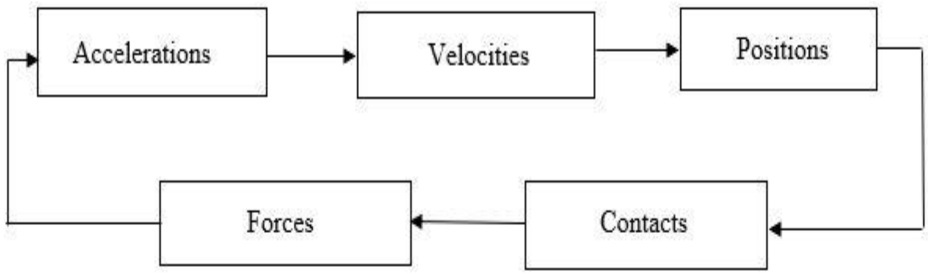

Fig. 2 Workflow of DEM simulation

Using suitable DEM tool, simulations are performed as per the Taguchi array. Time step is one of the important parameters in simulation process. The Rayleigh time step is given by following equation [7],

$$T_R = \frac{\pi R(\rho / G)^{\frac{1}{2}}}{0.1631\upsilon + 0.8766}$$

Where, T_R is the Rayleigh timestep, R is the particle radius, ρ is the density, G is shear modulus, υ is the poisson's ratio of particle. Time step is of critical importance in DEM simulations. It should be chosen sufficiently small so as to prevent excessive overlap which results in unrealistically high forces and avoid effects of disturbance waves. The typical time step for discrete element simulation is in the range of $1e^{-4}$ to $1e^{-6}$. As time step depends on shear modulus, higher the value of G, lower the timestep to achieve stability and longer it takes to complete the simulation. Based on particle material properties, software calculates the timestep automatically and provides a value of timestep. It is good practice to use 20 to 30 percentage of this calculated value. For current project work 25 percentage of calculated time step is used for simulation.

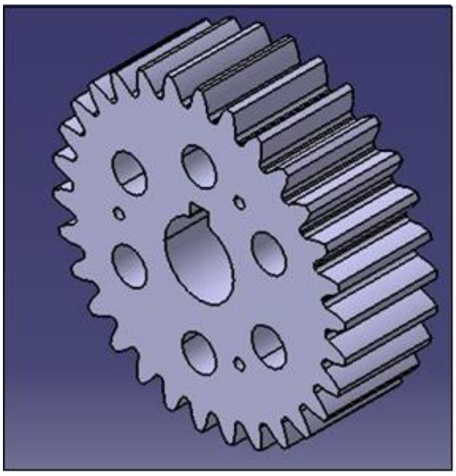

Fig. 3 CAD model of Gear

Following figure 4 shows the particle filling percentage for 1 mm radius of steel balls, Figure 4 (a) shows less than 50 percentage (200 balls); figure 4 (b) shows nearly 50 percentage (400 balls) and figure 4 (c) indicates more than 50 percentage filling (600 balls).

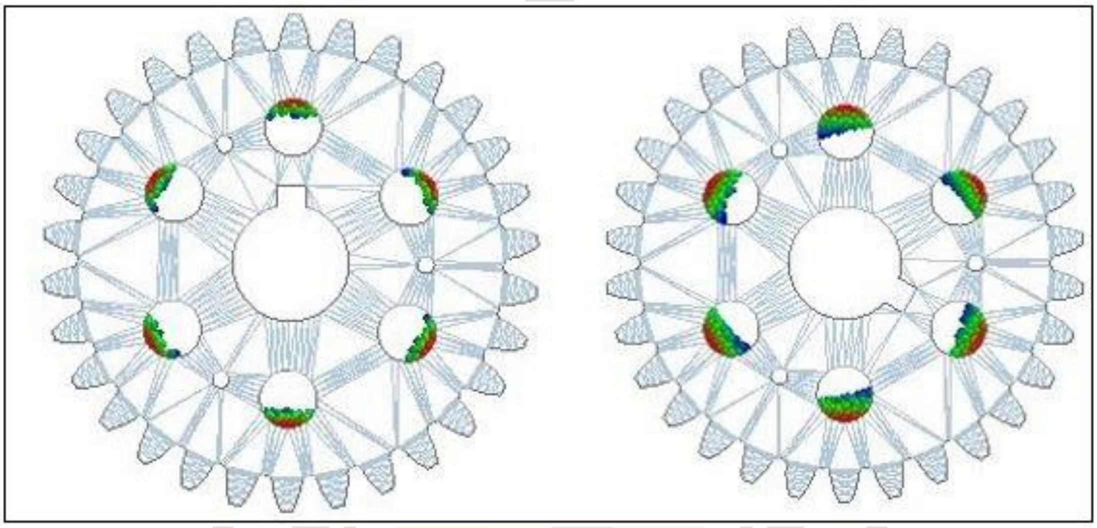

Fig. 4 (a) < 50 % and (b) 50 % particle filling rate

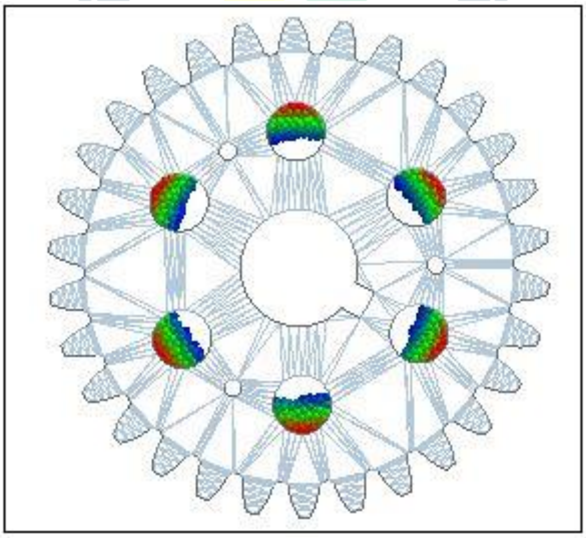

Fig. 4 (c) > 50 % particle filling rate

Similarly, simulations are carried out by replacing 1 mm radius steel ball with 2 mm and 3 mm radius steel ball. Particle filling percentages is varied in similar manner from less than 50 % to more than 50 %. After performing simulations for all above three cases, following total energy results are obtained.

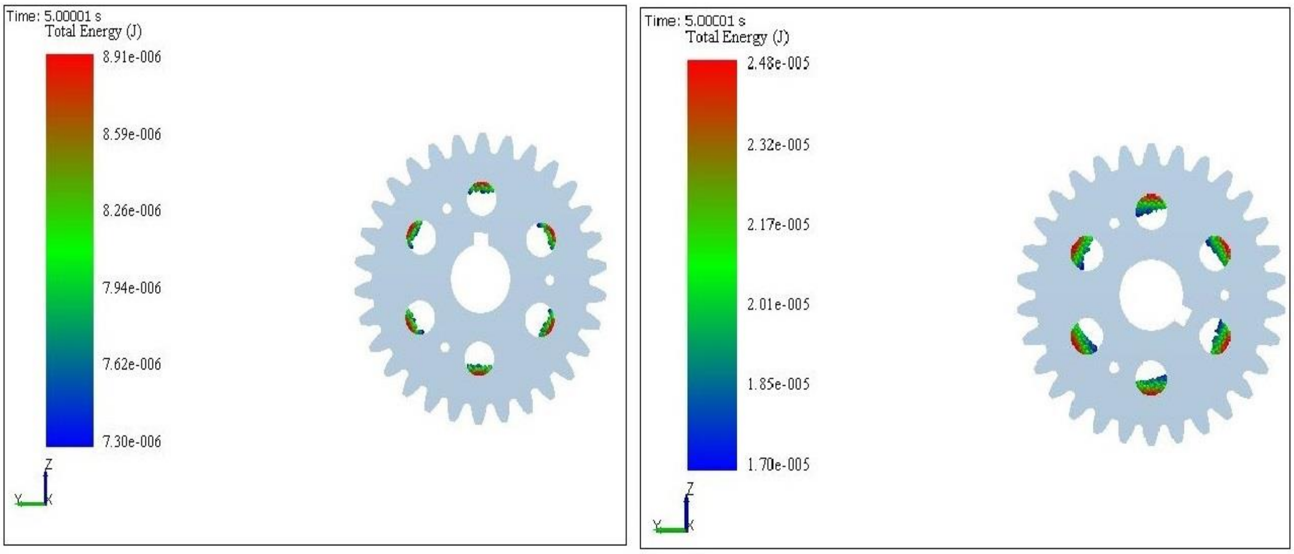

Fig. 5 Total energy for test run 1 and 2

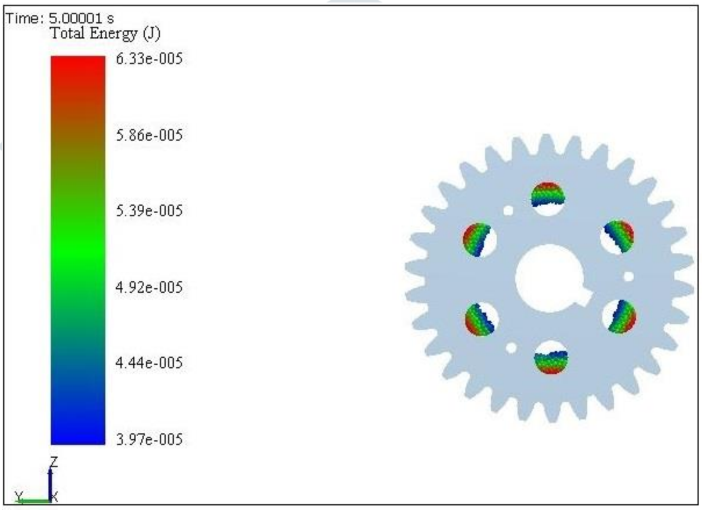

Fig. 6 Total energy for test run 3

V. RESULTS AND INTERPRETATIONS

All nine test runs are simulated using DEM tool. Results of energy dissipation are tabulated as follows.

Table 3 Total energy for respective test cases

Test Run	Parameter A	Parameter B	Speed in rpm	Total energy
	Radius of steel ball (mm)	Particle filling in Percentage		(J)
1	1	<50	300	$8.9e^{-6}$
2	1	50	500	$2.48e^{-5}$
3	1	>50	800	$6.33e^{-5}$
4	2	<50	300	$6.79e^{-5}$
5	2	50	500	$1.89e^{-4}$
6	2	>50	800	$4.83e^{-4}$
7	3	<50	300	$2.18e^{-4}$
8	3	50	500	$6.06e^{-4}$
9	3	>50	800	$3.55e^{-3}$

From above result table 6.2, if radius of steel ball kept constant and particle filling percentage is increased from less than fifty percentage to more than fifty percentage, the total energy associated with particles increases. Also, it shows that as speed increases, total energy value also increases. Steel balls(particles) dissipates energy through friction and inelastic collisions. Depending on collisions of particles, energy dissipation increases or decreases. As the rotational speed increases the centrifugal force on particle increases which results in increase in the normal force and friction at the contact points between particles and particles and gear hole wall.

VI. CONCLUSION

Particle damping technique studied with two important parameters such as particle size (Radius of steel ball) and particle filling percentage. Same material particles used throughout the simulation. Following conclusions can be drawn.

a. It is concluded from simulation results that particle size and particle filling percentage has significant impact on energy dissipation.
b. For same particle size (Radius of steel ball constant), if particle filling percentage is increased then total energy dissipation also increases. For increase in particle filling percentage from less than 50 % to more than 50 %, the energy dissipation increases by 10 times.
c. If particle size increased, energy dissipation found to be increased. The increase in energy dissipation is 1000 times more for 3 mm radius steel ball as compared to 1 mm radius steel ball.
d. With increase in speed along with the particle filling percentage, simulation results show that total energy dissipation increases.
e. These results can give theoretical basis for application of particle damping under centrifugal load in gear transmission.

VII. ACKNOWLEDGEMENT

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VIII. REFERENCES

[1] Zheng Lu, Zixin Wang, Sami F. Masri, Xilin Lu, “Particle impact dampers: Past, present, and future”, Structural Control Health Monitoring, wileyonlinelibrary.com/journal/stc,2017.

[2] Yanchen Du, “A spring-supported fine particle impact damper to reduce harmonic vibration of cantilever beam”, Advances in Mechanical Engineering, SAGE, 2017.

[3] Wangqiang Xiao, Yuxiang Huang, Hong Jiang, Hong Lin, Jiani Li, “Energy dissipation mechanism and experiment of particle dampers for gear transmission under centrifugal loads”, Particuology, 2016.

[4] WangqiangXiao, JianiLi, ShengWang, XiaomengFang, “Study on vibration suppression based on particle damping in centrifugal field of gear transmission.” Journal of sound and vibration,2015.

[5] Chao Zhang, Tianning Chen, Xiaopeng Wang and Kunpeng Yu, “Influence of cavity on the performance of particle damper under centrifugal loads”, Journal of Vibration and Control, SAGE, 2014.

[6] Tushar A Jadhav and Pradeep J Awasare, “Enhancement of particle damping effectiveness using multiple cell enclosure”, Journal of Vibration and Control, SAGE, 2014.

[7] www.edemsimulation.com/resources-learning/ebooks/