Effect Analysis of Gear Particle Damping in Transmission Gearbox

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Abstract -

Particle damping technology is a passive vibration control technology, which is based on the theory of energy dissipation mechanism. Damping is an influence within or upon an oscillatory system that has the effect of reducing, restricting or preventing its oscillations Active and passive damping techniques are common methods of attenuating the resonant vibrations excited in a structure. This paper represents the particle damping technology to reduce the vibrations generated in transmission gear. It has been observed that the variation of the driving gear's rotational speed and acceleration is far less than that of driven gear's. Putting particles into the driven gear can achieve a better damping effect. By simulation and experimental validation, we come to conclusion that we observed better damping effects for particles with diameter 4~5mm. This reduces the noise and harshness and improves the quality performance and life span of the gearbox.

Key Words: Particle Damping, Vibrations, Damping effect, Noise and harshness,

1. INTRODUCTION

As we know gear is a rotating element of a machine having cut teeth, which mesh with another toothed part to transmit torque. Gears are used to change the speed, torque, and the direction of power source. When two or more gears meshed in sequence it is termed as gear train or gear transmission. As gear transmission tending to be high speed, heavy duty, and high reliability, more severe demands for the dynamic performance of the gear transmission are put forward. As the teeths are always in meshing during running condition, there are always chances of vibrations in the machine/equipment. The vibration caused by gear transmission is the main source of the noise for most machinery and equipment. Therefore, to figure out how to control the vibration and noise of gear transmission will exert a significant influence on the precision, performance and life of the machinery, the protection for operators alike.

1.1 Vibration Control Techniques

There are different methods to control vibration and can be divided into three main categories, namely, passive, active, and hybrid vibration control. Active and passive damping techniques are common methods of attenuating the resonant vibrations. Passive vibration control systems function without external assistance, e.g., they do not require a power source, simply because they are driven by the vibration itself. In most cases, they offer the simplest and cheapest solution to the problem.

2. METHODOLOGY

As we know, gears are used in the industries to change the speed, torque, and the direction of power source. As gear transmission tending to be high speed, heavy duty and high reliability, the performance of the gear transmission needs to be very high. The vibration caused by gear transmission is the main source of the noise for most machinery and equipment. It has been observed that, in running condition vibrations introduced in the transmission gear which generates noise and harshness and adversely affects the performance of the whole gearbox. We will use passive vibration control method to reduce the vibrations i.e. particle damping technology. The particle damping is a combination of the impact and the friction damping. Change in the vibrations generated in the transmission gear can be calculated by analytically and by simulation. We will compare the results of both by doing experimental validation.

3. PARTICLE DAMPING TECHNIQUE

Particle damping technology is a passive vibration control technology, which is based on the theory of energy dissipation mechanism. Damping effect is mainly caused by the in elastic collision and friction of particles filled in the cavity, realizing the function of vibration reduction for the mechanical system. The advantages of particle damping include a prominent damping effect, resistance to heat and harsh environment, little modification to the original structure, and little associated mass etc. Introducing particle damping technology into gear transmission will effectively reduce the vibration from gear engaging, especially for harsh working conditions, such as high temperature and oil lubrication. Based on damping mechanism, the technology uses particles as the damping media. By friction and inelastic collision of damping particles being put into the cavities of the machinery, the vibration and noise can be reduced. This technology has the advantage of owning a remarkable damping effect, resisting high temperature, having little modification of the original structure, and adding less mass to the machinery. At present, the technology has become one of the frontiers of the vibration suppression field, and has been widely used in many fields.

3.1 DISCRETE ELEMENT METHOD

The discrete element method (DEM) is used to analyze the dynamics and kinematics of damping particles. In this paper, we have adopted DEM as the numerical simulation method to calculate the energy dissipation of the particle damper. As first step, the model of the gear pair has been established as the carrier of the particle damper. Secondly, under different rotational speed and load, the dynamic analysis of the gear pair has been carried onto get the performance of the centrifugal field of gear transmission. Then, the value of energy dissipation of particle dampers with different particle sizes in varied centrifugal fields has been calculated based on DEM.

3.2 GEAR MODEL

Fig. 1 shows the model of the particle dampers. There are eight equidistant holes made on the gear with lid and cover attachment.

Fig. 1: The Gear Model

3.2 CALCULATION OF THE EQUIVALENT PARAMETERS

The material used for gear is 40 Cr. There are 8 lightening holes in the web of the gear, with the diameter of 15mm. In addition, there are four bolt holes in the web, for the use of fixing the plate cover in order to seal the lightening holes.

The equivalent stiffness coefficient is a function of the equivalent mass, which can be expressed as

$$K_n = n^2 (M_n + m_d) = 4\pi^2 f_n^2 (M_n + m_d)$$

Where, n is rotational speed, m_d is the mass of the dampers and f_n is the equivalent fundamental frequency of the gear system.

The normal elastic coefficient is determined by the Hertz contact theory:

$$k_n = \frac{4}{3}\left(\frac{1-v_i^2}{E_i} + \frac{1-v_j^2}{E_j}\right)^{-1}\left(\frac{R_i+R_j}{R_iR_j}\right)^{-1/2}$$

4. DISCRETE ELEMENT METHOD SIMULATION

Fig. 6.1 shows the driven gears rotational speed curve at different load when the driving gear's rotational speed is fixed. The rotational speed of the driven gear increases with the start of the motor during 0–0.1s. After 0.1s, the rotational speed remains approximately a constant value.

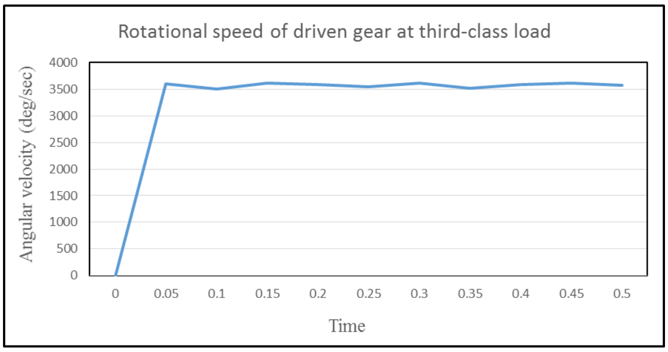

Fig. 2(a): Rotational speed of driven gear at third-class load

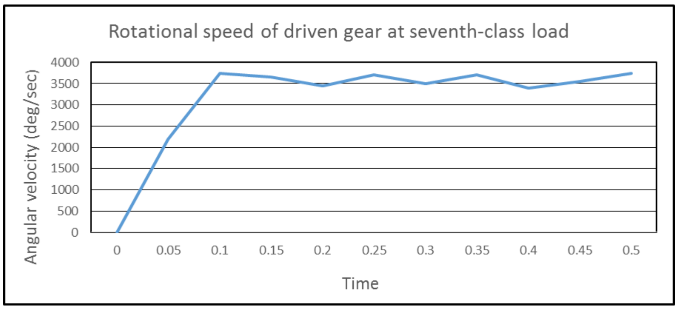

Fig. 2(b): Rotational speed of driven gear at seventh-class load

Fig.3 shows Angular acceleration under different class loads. The acceleration variation can be transformed as the excitation on the tooth surface, which is defined as the boundary condition of the particle dampers and will be used in the following discrete element analysis.

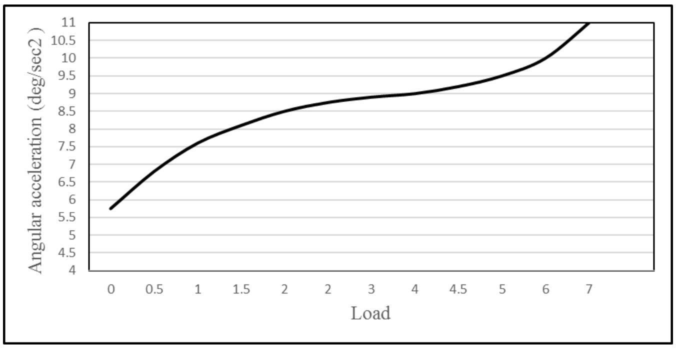

Fig. 3: Angular acceleration under different load classes

4.1 MOTION OF PARTICLES

Particles are made of stainless steel. Fig. 4 shows the diagram of particles with different diameter size filled in the lightening hole.

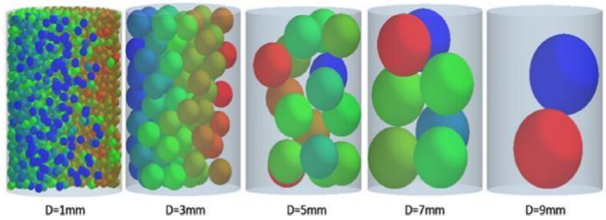

Fig. 4: Particles with different diameters filled in the lightening hole

4.2 THE INFLUENCE OF PARTICLE SIZE ON THE DAMPING EFFECT AT DIFFERENT LOADS

In order to study the influence of particle diameter on the damping effect at different load, we choose stainless particles with the diameter of 1 mm, 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm. Some parameters of the particles are: density ρ = 7850 kg/m3, Poisson's ratio ν = 0.28, shear modulus G = 77 GPa, Young's elastic modulus E = 206 GPa, filling rate ψ = 60%. The rotational speed of the gear is fixed as 600 rpm and the load exerted on the driven gear is set from first-class to seventh-class.

Fig. 5 shows the histogram of particle dampers' energy dissipation with different particle diameters at 600 rpm, second- class load. Though the total energy dissipation is different at each time point, the overall trend is similar. At about 0.0215 s, a peak appears. Such an energy peak is a result of the excitation from gear's time-varying meshing stiffness. And it levels off gradually along with the disappearance of the gear excitation. At 600 rpm, the period of a single tooth engagement is 0.0042 s for the gear with 24 teeth. As is discussed in Section 3, the excitation rises and falls cyclically. That is to say, the next excitation will occur in approximately 0.0257 s, which meets the results of the simulation.

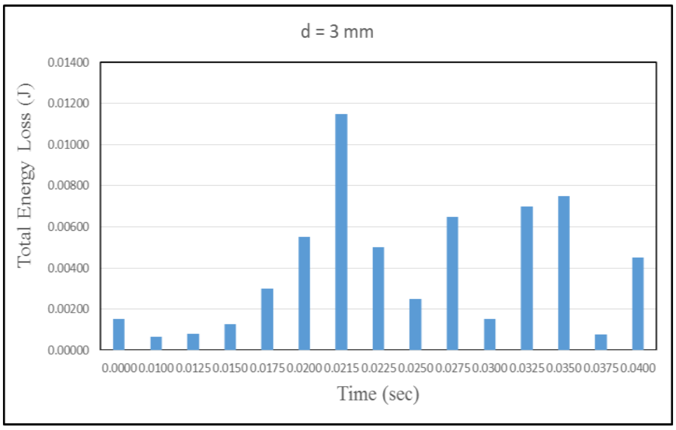

Fig. 5 (a): the Energy Dissipation Trend (d=3mm)

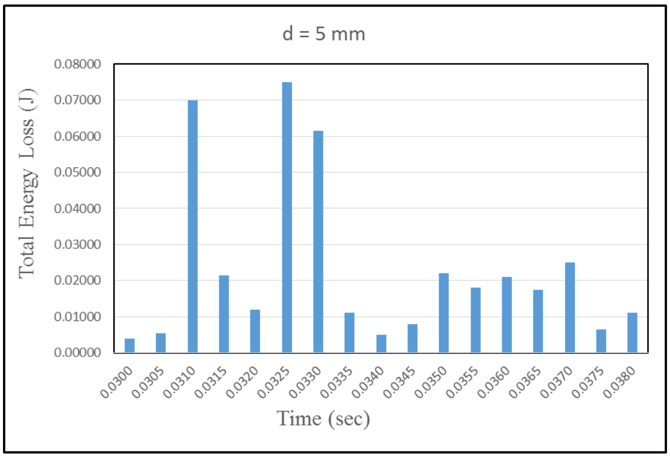

Fig. 5 (b): the Energy Dissipation Trend (d=5mm)

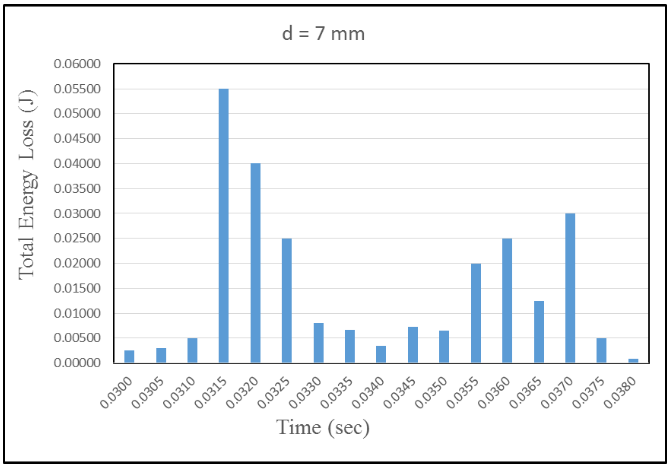

Fig. 5 (c): the Energy Dissipation Trend (d=7mm)

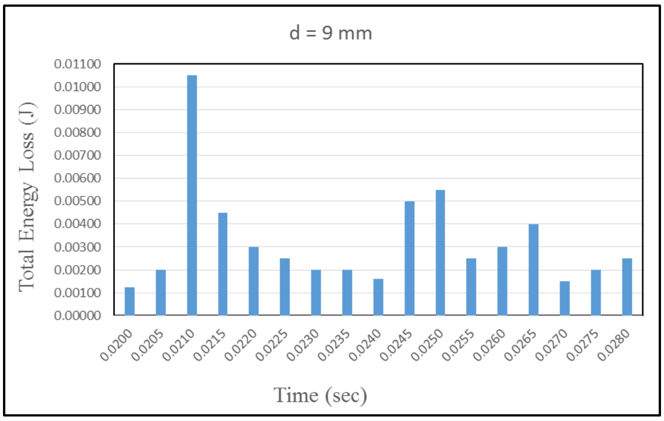

Fig. 5 (d): the Energy Dissipation Trend (d=9mm)

5. EXPERIMENTAL VALIDATION

5.1 EXPERIMENTAL SETUP

The experiment equipment includes four modules as mentioned below (shown in fig. 6).

1. The gear transmission system (Gearbox)
2. The exciting device
3. The acceleration sensor and
4. The data analytical equipment.

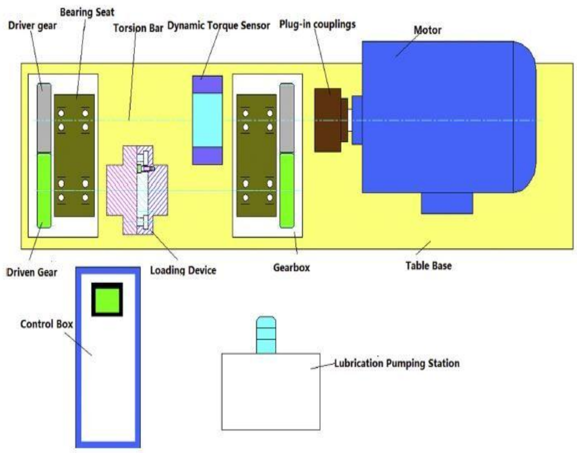

Fig. 6: Experiment Set-up

5.2 EXPERIMENTAL VALIDATION

We get the acceleration of the gear filled with particles under varied load and rotational speed by experiment, which is expressed as a_{pij}. Likewise, the acceleration of the gear without particles is expressed as a_{eij} Use the factor D_e to indicate the damping effect, which is expressed as,

$$D_e = 1 - \frac{(\int a_{xpij}\,dt)^2+(\int a_{ypij}\,dt)^2+(\int a_{zpij}\,dt)^2}{(\int a_{xeij}\,dt)^2+(\int a_{yeij}\,dt)^2+(\int a_{zeij}\,dt)^2}$$

The damping factor of the particle dampers can be defined as,

$$D = \frac{E_i - E_o}{E_o}$$

Where, E_o is the kinetic energy of the system before adding particles and E_i is the kinetic energy of the system after adding particles.

E_o and E_i can be expressed as,

$$Eo = \frac{1}{2} M_t \left(v_{xo}{}^2 + v_{yo}{}^2 + v_{zo}{}^2\right)$$

$$Ei = \frac{1}{2} (M_t + m_t)\left(v_{xi}{}^2 + v_{yi}{}^2 + v_{zi}{}^2\right)$$

Where, M_t is the mass of the driven gear and m_t is the total mass of the particles.

Also $m_t << M_t$.

Comparison of the gear's acceleration with and without particle dampers is shown in Fig. 7. The dampers do reduce the acceleration of the gears, which also means the vibration is reduced by dampers. We can also get the information from the figure that the ratio of the reduced acceleration increases with the increase of rotational speed. At 600rpm, the dampers reduce about 20% acceleration whereas at 1200rpm, the dampers reduce more than 30% acceleration.

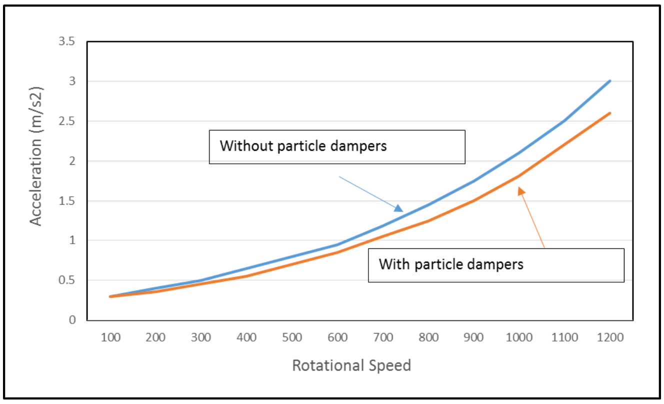

Fig. 7: Gear's acceleration with and without particle dampers

6. CONCLUSIONS

By analysis of the gear transmission, we got the source of the vibration of the gear pair and the boundary condition of the centrifugal field of the gear transmission the dampers being set in. Through theoretical calculation, simulation analysis and experiment, the particle damper's damping mechanism has been obtained. The conclusions drawn are mentioned as below,

1. The vibration frequency and the excitation frequency derived from the modal analysis of the gear are not relevant, and therefore no resonance occurs.
2. By comparison, the variation of the driving gear's rotational speed and acceleration is far less than that of the driven gear's, which suggests the main source of the vibration is the driven gear.
3. Putting particles into the driven gear can achieve a better damping effect. The optimum particle diameter is 4–5 mm under whatever condition. The optimum diameter in experiment is slightly different from that in simulation. Such discrepancy can be explained by the changed characteristic of the system due to additional apparatuses in experiment.
4. Choosing an optimal particle diameter will help to effectively reduce the vibration of gear system for different rotation speed and loads.

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