Mechanism and Machine Theory 108 (2017) 217–230

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

Investigation into the influence of particles' friction coefficient on vibration suppression in gear transmission

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ARTICLE INFO

Keywords:
Gear transmission
Discrete element method
Particle damping
Centrifugal field
Friction coefficient

ABSTRACT

The vibration from gear engagement is the main source of the noise and vibration of reducers under heavy load and high speed. In order to dissipate the energy as well as suppress the vibration, we introduce the particle damping technology into gear transmission. In this paper, the model of the particle dampers is built in the inherent lighting holes of the gear. By dynamic analysis of gear transmission, the boundary conditions of the centrifugal field are obtained. Then we use the discrete element method to analyze the kinematics and dynamics of the damping particles and determine the relationship between energy dissipation and friction coefficient (surface roughness) of the particles at different rotational speed and load. We come to the conclusion from simulation results that at low rotational speed, smoother particles has better damping effect, while at high speed, rougher particles are better. There is no evident relation between the load and the coefficient of static friction. Finally, the simulation results are verified by experimental results. This conclusion will provide theoretical basis for engineering practice.

1. Introduction

The time-varying mesh stiffness is the main reason for the vibration and noise of gear transmission, causing damage to machineries and shortening the life of the devices [1–4]. Thus, suppressing the vibration and noise from gear transmission will greatly improve the reliability and comfort as well as the life of reducers.

Vibration suppression for gear transmission can be divided into active vibration suppression [5] and passive vibration suppression [6]. Active method suppresses vibration by improving the gear manufacture precision, by tuning parameters, or by modifying tooth. However, excitation and time-varying stiffness cannot be eliminated even by optimizing the structure and gears' parameters [7–9]. Besides, active vibration suppression has the drawback that even suppress little vibration using active method will lead to great manufacturing cost and cumbersome calculation and design [10–14]. On the other hand, passive vibration suppression method dissipates the energy from gear transmission by energy-consuming equipment. Such energy is partly dissipated by other equipment, resulting in the reduction of vibration and noise. The study on the passive vibration suppression of gear transmission is relatively rare, mainly focusing on the study of viscoelastic damper and friction damper [15].

The particle damping technology is a kind of passive vibration suppression technology [16,17]. 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 [18–22]. 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

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http://dx.doi.org/10.1016/j.mechmachtheory.2016.10.015
Received 20 November 2015; Received in revised form 19 October 2016; Accepted 24 October 2016
Available online 18 November 2016
0094-114X/

many fields. However, the particle damping technology in the field of gear transmission has not been studied thoroughly. Thus, applying the particle damping technology into gear transmission will fill this gap.

The discrete element method (DEM) [23] is used to analyze the dynamics and kinematics of damping particles. This method was proposed by Cundall and Atrackz in 1979 as a numerical calculation method of discrete particulate matter's motion [24]. Different from the calculation method of continuum [25] and particulate matter [26], the calculation method of discrete particulate matter [27] is based on Newton's second law rather than the minimum potential energy principle [28]. DEM uses soft-ball model, calculating contact force by the overlap of contacting particles and updating the movement and position of all the particles at every calculating time point [29–31].

There are many factors that will affect the damping effect of particles, such as the diameter, the material, the friction coefficient and the restitution coefficient of the particles, as well as the filling rate of the damper [32,33]. Because the friction coefficient directly affects the tangential (friction) energy dissipation of the damper and indirectly affects the normal (collision) energy dissipation, it has an important influence on the total energy dissipation of the damper. In order to find the influence rule of the friction coefficient on the damping effect, we simulate the movement of the damping particles under different rotational speed and load. By comparing the simulation trend of energy dissipation and the tested trend of the damping factor [34–36], we come to the conclusion that the energy dissipation and vibration from gear engagement increase with rotational speed while the increase of the load cannot achieve an unlimited increase of the energy dissipation of dampers and larger load will cause the decline of the damping effect; at low rotational speed (below 300 rpm), smoother particles (with coefficient of static friction below 0.2) has better damping effect, while at high speed (above 700 rpm), rougher particles (with coefficient of static friction above 0.5) are better. There is no evident relation between the load and the coefficient of static friction. This conclusion will provide theoretical basis for engineering practice.

2. DEM model description

2.1. Gear model

Fig. 1 shows the model of the particle dampers (There are eight dampers in Fig. 1). We put particles into the lighting holes of the gear and cover the holes with lids. The gear rotates around the X-axis, and particles start to move, resulting in the collision and friction with each other and with the damper wall. Due to the existence of centrifugal force, particles will cling to the damper wall once starting to move. We know that the natural frequency of the gear system changes correspondingly with rotational speed, and the equivalent mass of the gear system is a function of the natural frequency, therefore, the equivalent mass is a function of the rotational speed. In fact, all the variables we are discussing change with rotational speed (will be discussed later), and accordingly, all the variables are expressed with a subscript of ‘n’, where' n' represents rotational speed. The governing equation of the gear system can be expressed as

$$M_n \frac{\mathrm{d}^2 \boldsymbol{X}_n}{\mathrm{d}t^2} + C_n \frac{\mathrm{d}\boldsymbol{X}_n}{\mathrm{d}t} + K_n \boldsymbol{X}_n = \sum \boldsymbol{F}_n + M_n \boldsymbol{g} \tag{1}$$

where M_n is the equivalent mass of the gear system, C_n is the equivalent damping coefficient of the gear system, K_n is the equivalent stiffness coefficient of the gear system, $\boldsymbol{X}_n$ is the displacement matrix of the gear system, $\sum \boldsymbol{F}_n$ is the resultant force particles are acting upon the gear wall, $\boldsymbol{g}$ is ground acceleration.

As mentioned above, the equivalent mass, equivalent damping coefficient as well as equivalent stiffness coefficient changes with rotational speed, resulting in different energy dissipation behavior of the particle dampers. Thus, we need to find out how the parameters change under varied rotational speed in order to get the rule of energy dissipation behavior of the dampers.

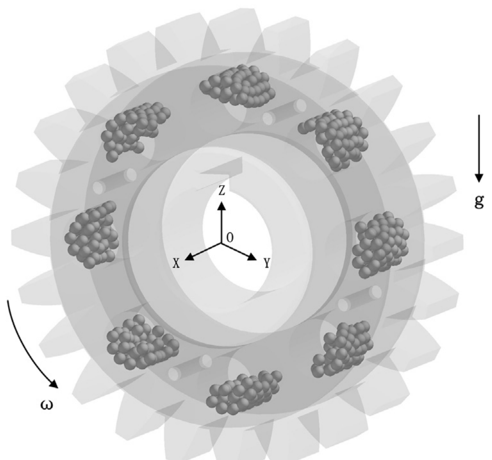

Fig. 1. Model of the particle dampers.