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Research on the impact of surface properties of particle on damping effect in gear transmission under high speed and heavy load

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ABSTRACT

The vibration and noise from gear transmission have great damage on the mechanical equipment and operators. Through inelastic collisions and friction between particles, the energy can be dissipated in gear transmission. A dynamic model of particle dampers in gear transmission was put forward in this paper. The performance of particle dampers in centrifugal fields under different rotational speeds and load was investigated. The surface properties such as the impact of coefficient of restitution and friction coefficient of the particle on the damping effect were analyzed and the total energy loss was obtained by discrete element method (DEM). The vibration from time-varying mesh stiffness was effectively reduced by particle dampers and the optimum coefficient of restitution was discovered under different rotational speeds and load. Then, a test bench for gear transmission was constructed, and the vibration of driven gear and driving gear were measured through a three-directional wireless acceleration sensor. The research results agree well with the simulation results. While at relatively high speed, smaller coefficient of restitution achieves better damping effect. As to friction coefficient, at relatively high speed, the energy dissipation climbs up and then declines with the increase of the friction coefficient. The results can provide guidelines for the application of particle damper in gear transmission.

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 [6,34,35,43]. 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 [7–9,31]. 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

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on the passive vibration suppression of gear transmission is relatively rare, mainly focusing on the study of viscoelastic damper and friction damper [15,39].

The particle damping technology is a kind of passive vibration suppression technology. Based on damping mechanism, the technology uses particles as the damping media [45–47]. By friction and inelastic collision of damping particles being put into the cavities of the machinery, the vibration and noise can be reduced [16–18]. This technology has the advantage of giving a remarkable damping effect, resisting high temperature, requiring little modification. At present, the technology has become one of the frontiers of the vibration suppression field, and has been widely used in many fields. However, the particle damping technology in the field of gear transmission has not been studied thoroughly [40,41]. Thus, applying the particle damping technology into gear transmission will fill this gap [42]. By filling the lightening hole with particles, we obtained a particle damper, which can provide resistance to the vibration and consume the energy.

The discrete element method (DEM) is used to analyze the dynamics and kinematics of damping particles [37,38,44]. This method was proposed by Cundall and Atrackz in 1979 as a numerical calculation method of discrete particulate matter's motion [19,20]. Different from the calculation method of continuum [21] and particulate matter [22], the calculation method of discrete particulate matter [23] is based on Newton's second law rather than the minimum potential energy principle [24]. 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 [25–27].

There are many factors that will affect the damping effect of particles, such as the diameter, the material, the friction coefficient and the coefficient of restitution of the particle, as well as the filling rate of the damper [28,29,33]. Because the coefficient of restitution directly affects the collision energy dissipation of the dampers, while the friction coefficient affects the friction energy [30,32,36], the two coefficients have a vital influence on the total energy dissipation of the dampers. And that's the main mission of the paper – to find the two impact rule.

2. Discrete element model

Contact between the particles engenders the normal force by collision and the tangential force by friction. Considering the calculation accuracy and speed, a Hertz-Mindlin soft sphere model is chosen in this paper. The normal force can be simplified as a spring damper by a linear contact model. The tangential force can be simplified as a spring damper and a sliding friction damper, thus can be calculated by Coulomb friction mode. A gear equipped with particle damper in the lightening hole is shown in Fig. 1, in which the contact force model between particles and between particle and the damper wall are also presented.where k_n is the normal stiffness and c_n is the normal damping of the particle, k_t is the tangential stiffness and c_t is the tangential damping of the particle.

The step and simulation procedure for DEM simulation are presented in Fig. 2.

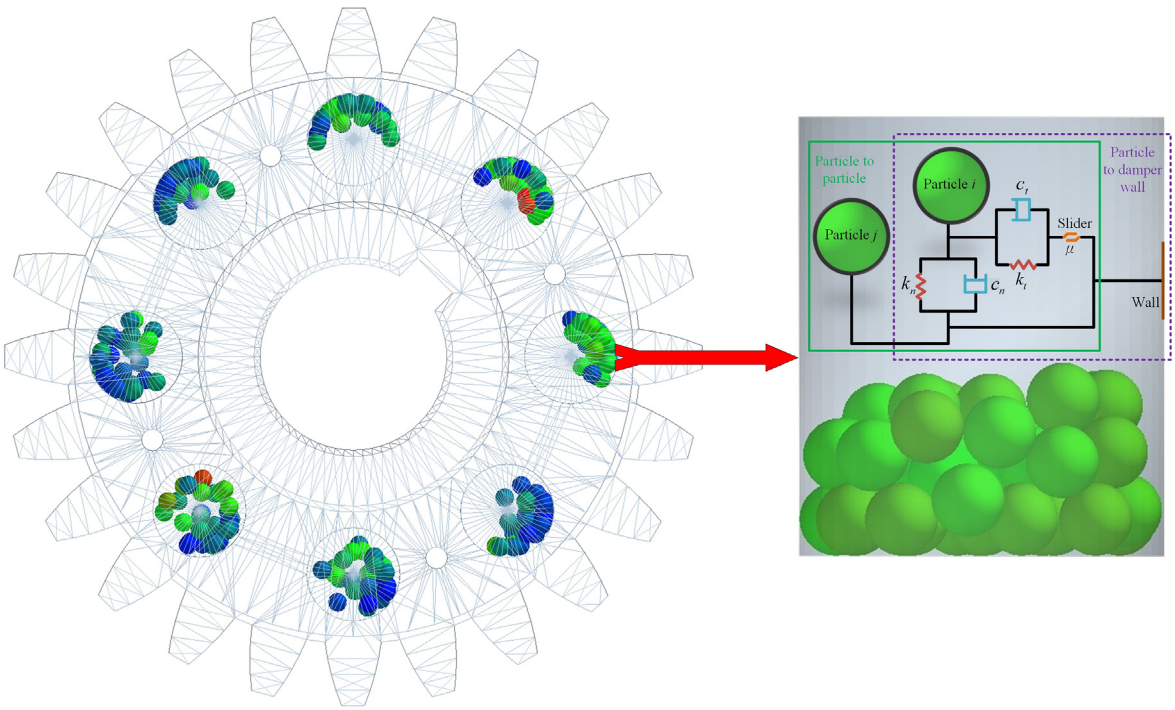

Fig. 1. Gear model equipped with particle dampers.