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Tooth profile modification based on lateral- torsional-rocking coupled nonlinear dynamic model of gear system

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ABSTRACT

In this paper, the influence of tooth profile modification on the vibration of a single gear is studied. Considering geometric eccentricity, gyroscopic moment, teeth to the partial load torque and backlash, a 10 degree of freedom (DOF) lateral-torsional-rocking coupled nonlinear dynamic model of a single gear system is proposed. Considering actual motion state and tooth profile modification, stiffness of the meshing model was studied using an analytical method. Results show influence of the modification amount with different modification types and different modification length on dynamic load. For the case of different modification lengths and modification types, with increasing modification amount, profile of dynamic load coefficient follows a 'V' type pattern. An optimal modification amount can be determined, where dynamic load of gear can be minimized. At the same time, when modification amount exceeds a certain critical value, dynamic load for modified gear was higher than the dynamic load for gear without modification. The optimum modification can effectively slow mutation of meshing stiffness and reduce the dynamic load of gear; the meshing force amplitude of modification gear is decreased significantly in the high order frequency, while the impact load caused by the alternation of single and double teeth is slowed down, and contact rate is basically unchanged.

1. Introduction

Gear modification plays a key role to reduce vibration and noise, thereby allowing improvement in the overall reliability of the gear system. Gear modification can be carried out using tooth profile and axial modification. Tooth profile modification for gear modification has been more widely used. Tooth profile modification resolves issues related to change in meshing stiffness, which is caused due to change in the number of meshing teeth. Thus, by changing tooth profile, meshing impact can be lowered, which results in reduced vibration and noise in the gear system.

Vibration and noise for gear meshing are typically observed in dynamic state. Modification parameters of optimal static characteristics enables the dynamic characteristics to achieve the optimum are proved to be difficult and often unsuccessful. In order to accurately analyze vibration reduction effect of gear modification, a combination of gear modification and dynamic analysis of the gear system is needed. This method also provides a reliable basis for choosing parameters for tooth modification. The main objective while carrying out tooth profile modification is the determination of the three parameters: modification amount, modification length and modification type.

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Taking a gear dynamics model with a periodic time-varying meshing stiffness into consideration, Lin et al. [1,2] studied the influence of tooth profile modification on dynamic load of a gear system for low and high contact gear ratios. For a two-stage gear system and planetary gear system, Parker et al. [3,4] compared and analyzed effect of tooth profile modification on the dynamic characteristics. Here, different dynamics models were used and an in-depth analysis to characterize stability of the system associated with tooth profile modification was carried out. Marcello et al. [5] studied tooth profile modification parameters using a non-linear dynamics model. In this study periodic time-varying stiffness, clearance and other factors were taken into consideration. Based on the results, optimization design method to minimize dynamic transmission error was proposed. In addition to the above theoretical study, various research groups have carried out tooth profile modification experiments. Fernandez et al. [6] analyzed the influence of tooth profile and tooth profile error on dynamic characteristics of the system based on meshing stiffness calculations using a finite element contact model. Hua et al. [7] used a dynamic finite element method to study effect of tooth profile modification on the dynamic characteristics of a gear from an energy perspective for a helical gear system.

Considering a dynamic model of a multi-mesh idler gear system, Parker et al. [8] researched the effects of tooth profile modification on planetary gear dynamic. Chen et al. [9] introduced a mesh stiffness model to calculate mesh stiffness of a spur gear pair with tooth profile modification. The model establishes the relationship between the gear tooth errors and the total mesh stiffness. Basing on improved load distribution and reduced transmission errors, Vilmos Simon [10] presents a method to determine the optimal tooth modifications in hypoid gears. By applying the optimal tool parameters, the maximum tooth contact pressure and the angular position error are reduced. Zhang et al. [11] introduced a model for analysis of transmission errors of helical gears with modified tooth surfaces under load. The model accommodates the modification of tooth surfaces, gear misalignments and the deformation of tooth surfaces caused by contact load.

Previous gear modification methods take optimum of gear static characteristics as the research objectives, which is difficult to achieve optimum of gear dynamic characteristics. Based on the research reported in literature, dynamic model of a gear system is relatively simple and generally includes 2 degrees of freedom (DOF) nonlinear torsional vibration model. Therefore, basing on a lateral-torsional-rocking coupled nonlinear dynamic model, the research of gear modification with the optimal gear dynamic characteristics as the goal is of great significance. In addition, influence of tooth profile modification parameters on meshing stiffness calculated using FEM reduces algorithmic efficiency in previous works. In this paper, a 10 DOF lateral-torsional-rocking coupled nonlinear dynamic model was established for a single stage gear system. The model includes geometric eccentricity, gyroscopic moment, teeth to the partial load torque and backlash. A meshing stiffness model of a spur gear was developed to involve tooth profile modification and actual motion state of the gear. The model was evaluated based on calculated meshing stiffness using an analytic method. Basing on the gear dynamic model and taking optimum of gear static characteristics as the objectives, the influence of profile modification parameters on meshing stiffness is studied for a heavy-load vehicle gear system with engine excitation. The influence of tooth profile modification parameters on dynamic load is obtained. The effect of modification on the contact ratio is analyzed. Under the conditions of constant modification length and linear modification respectively, the optimal modification amount which minimizes the dynamic load coefficient is obtained. This study can be used to guide the design of gear systems with low vibration and low noise.

2. Dynamic model

In this paper, a gear system dynamic model has been established for a single stage gear system, as shown in Fig. 1. The following assumptions were made to establish the dynamic model:

1. Gear wheel body was simplified as a rigid body and gears were coupled together by meshing force.
2. Effect of rocking DOF on contact line along the tooth width direction was neglected, meshing surface and base circle of two gears tangent to each other.

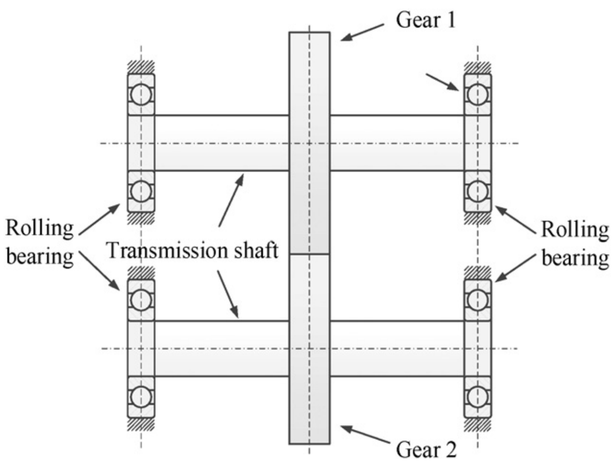

Fig. 1. Single stage gear system.