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Research paper

# Optimization design on dynamic load sharing performance for an in-wheel motor speed reducer based on genetic algorithm

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ABSTRACT

With the help of the genetic algorithm search technique as well as the two-dimensional simplified model of floating planetary gear set, the optimal design of the dynamic load sharing performance for an in-wheel motor planetary gear reducer is completed. Based on the internal and external incentive factors, the formula for calculating the average load factor is derived. Through the numerical calculation of the dynamic response of the planetary gear set, several design parameters which have significant influence on the performance of the reducer is determined. In the optimization process, a program based on Ishikawa algorithm to express the time-varying meshing stiffness in the dynamic equations for the optimization is achieved. The multi-objective including load sharing performance and volume optimization method is established. A comparison study on the single optimization is also carried out in this work. The research results and the optimization program can help the designer to improve the dynamic performance as well as the design properties of the planetary gear set.



## 1. Introduction

In the field of vehicle engineering, especially in off-road vehicles, the in-wheel motor speed reducer has a wider application prospect. Due to the driving requirements of off-road vehicles, the vehicle must have a higher transmission ratio and a larger clearance from the ground. The vehicle equipped with in-wheel motor speed reducer has no need of a gearbox and main reducer, this will make the chassis more simple and realize a higher chassis height relatively, which makes the vehicle have a better performance in off-road conditions.

In general, the in-wheel motor speed reducers can be classified into three types according to the type of reducer. They are the taper planetary gear, the cylinder planetary gear and the cycloid gear. A planetary gear reducer of in-wheel motor is taken as the study object owing to its excellent characteristics such as high torque ratio, compactness and excellent bearing capacity. During all the performance of planetary gear, the load sharing performance plays an important role in transmitting power. However, because of the inevitable manufacturing errors, installation errors and the elastic deformation of component factors, etc., the load distribution between planets gear is uneven, which will lead only one planet gear in load condition seriously. If this load condition continues, the gear tooth will appear easily to be broken. Therefore, at the

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beginning of the planet gear system design, it's significant to give full play to the advantages of planetary gear train and extend the service life by fully considering various influence factors.

There have been a number of many experimental and theoretical researches on planetary gear load distribution which has a lot to do with manufacturing errors (gear operation error, error of tooth thickness, planetary shaft hole position error, etc.), planetary shaft support stiffness, bearing clearance, the gear axis parallelism, rim thickness, centrifugal force, etc. Kahraman [1] put forward a planetary gear dynamics analysis model which can be applied to contain an arbitrary number of planetary wheel, the size of the planet wheel and some error variable planetary system. The research took the sun gear support stiffness as a parameter to study the effect of other error of load distribution. Bodas and Kahraman [2] studied the impact of three assembly error on static load distribution of the planetary. They were the planetary shaft hole position error, the tooth thickness error and the gear running error. Singh [3] established the three-dimensional GASM finite element contact analysis model of planetary gear train and studied the influence of the planetary shaft hole position error on the load distribution with different number of planet gears. Research showed that the tangential position error of the planetary shaft hole had a great influence on load distribution. This effect was increasing with the increase in the number of planet gears. Cheon and Parker [4,5] studied the effect of the manufacturing errors and the support stiffness on the dynamic behavior of planetary gear train as well as the load distribution. In this paper, the manufacturing errors included the planetary shaft hole position error, the radial runout error, the gear thickness error were considered. Taking different support load of each gear as the basis for the calculation of load distribution, the quasistatic changes of the support force, the overload share ratio and the critical stress was studied when each gear was under the influence of the different support stiffness and the planetary gear hole position error independent or together. Ligata et al. [6] proposed an accurate calculation method of load distribution coefficient when considering planetary shaft hole position error as for closed planetary gear system. Each planet gear load distribution coefficient calculation formula was deduced when the number of planet gears was 3, 4 and 5. Those formulas and methods were verified by experiment and finite element analysis. Kahraman et al. [7] studied the influence of the thickness of the inner ring gear on the load distribution from the two aspects of the test and theoretical analysis. It was found that different gear ring thickness makes the load shared by each planet gears change. The number of planet gears and planet carrier errors were also considered. Montestruc [8] applied the cantilever beam theory and the finite element method to conclude that the load sharing performance of planetary gear supported by the small flexibility planet shaft was different from that supported by rigid planet shaft for the influence of planet stiffness on the load distribution.

Meanwhile, there have been a lot of studies attempting to optimize gears or gear reducers with the aid of computers. Savsani et al. [9] obtained the optimal combination of design parameters for minimum weight of a spur gear train with the help of two advanced optimization algorithms known as particle swarm optimization (PSO) and simulated annealing (SA). Tamboli et al. [10] analyzed the minimum volume optimization of the helical gear pair by using particle swarm optimization technique in order to get low weight energy efficient and cost effective system elements. Jiao [11] proposed a new optimization method which is based on the equal strength and the minimum volume of the planetary gears. The gear parameters of transmission are solved by using the condition of planetary gear assembly, the maximum fatigue stress and fatigue life of the planetary gear trains are obtained by using ROMAX software. Both the simulations and experiments show the effectiveness of the proposed method. Wang et al. [12] put forward a design optimization method based on genetic algorithm to obtain the combinatorial solution for achieving the comprehensive goal of minimum volume and maximum efficiency. Wang [13] proposed a new method to determine the dynamic model of a practical gear system through distinguishing the relation between the rotational movement of gears and the acoustical noise signal measured on the .gear tester. The tested result showed that the profile modification derived of the identified model can greatly reduce gear noise.

These studies referenced above highlights two important aspects regarding the topic of this work. Firstly, it is obvious that most of the references cited above focused on the influence of planetary gear system parameters of excitation on the load distribution based on certain kinematics analysis model, but few scholars can determine the optimum design parameters of load performance satisfied under the actual running conditions for a practical planetary gear. Secondly, most optimal designs of reducer aimed at volume, weight, efficient or noise which is rarely involved in dynamic performance. The aim of this work is to obtain the optimum design parameters of a planetary gear reducer applied in an off-road vehicle in-wheel motor with better dynamic performance.

In this paper, we attempt to establish a two-dimensional simplified model of a planetary gear set to deduce the calculation formula of the average load factor. The proposed model is nonlinear time-varying in which time-varying meshing stiffness and tooth frequency error are considered. Combined with the external load excitation, some factors associated with the load sharing performance are analyzed and the relevant design parameters are chosen as the optimization variables. A dynamic optimization model based on genetic algorithm is proposed. The main distinguish point is that the dynamic differential equations should be solved in each iteration optimization process and the time-varying meshing stiffness also varies with the change of the design variables. A program based on Ishikawa algorithm to express the time-varying meshing stiffness in the dynamic equations for the optimization is achieved. Both the multi-objective and single optimization are carried out. The research results and the optimization program can help the designer to improve the dynamic performance as well as the design properties of the planetary gear set.