Current Research Status of Gear Reducer

Lufang Qin, Lijuan Yang, Tao Sun
Xuzhou Institute of Technology, Xuzhou, China

ABSTRACT: To better design gear reducer, some research statuses are summarized that include optimal design of gear reducer, static and dynamic working performance of gear, fatigue-life prediction method and seal technology. Finally, some ideas of further developing gear reducer design technology are proposed.

1 INTRODUCTION

Gear reducer is mainly used to modify rotating speed, transmit power and output torque, which is widely used for many industries, such as oil production, mining, vessel, engineering machinery and so on. It can be of many different structures such as planetary gear reducer, double-circular-arc gear reducer, involute gear reducer, etc.

The aim of researching gear reducer design technology is to gain good properties such as greater transmission ratio, stronger carrying capacity, higher mechanical efficiency, more compact conformation, better seal, etc. In order to get this aim, some research statuses are summarized that include optimal design of gear reducer, static and dynamic working performance of gear, fatigue-life prediction method and seal technology. Finally, some ideas of further developing gear reducer design technology are proposed.

2 CURRENT RESEARCH TECHNOLOGY OF GEAR REDUCER

2.1 Optimal design technology

2.1.1 Single-objective optimal design

Volume and weight is an indicator of gear reducer, so many scholars has researched on this.

Under the condition of ensuring loading capacity, Liu et al. [1] optimized volume of gear reducer to obtain minimal volume of planetary gear reducer by using MATLAB optimal toolbox. The results showed that the method is feasible and correct, and the volume of planetary gear reducer by 23.7% under the condition of good transmission performance.

With NGW planetary gear reducer as physical model, number of teeth, module, tooth width, the sun wheel displacement coefficient and internal gear displacement coefficient as design variables, minimal volume as objective function, gear strength as constraint, Zhang et al. [2] introduced an uniform discretization processing algorithm of continuous variables and non-uniform discrete variables, calculations of which accorded with actual requirement.

According to machining accuracy and economy, Guan [3] et al. allocated transmission ratio of the small module secondary 2K-H planetary gear reducer. The minimal volume optimization of multistage planetary gear was transformed into optimization of single gear, with minimal volume of sun wheel of single planetary gear, planet wheel and internal gear as optimal objective, in which penalty function algorithm was adopted to gain optimal case.

With tooth width, diameter of big and small gear shafts and number of teeth, module, gear surface strength of small gear as design variables, and bending strength of big and small gears, their surface durability, their torsion strength, their center distance, their interference condition, their fatigue strength of gear surface, their tooth width-module ratio as constraints, minimal weight as objective, Savsani et al. [4] respectively adopted particle swarm optimization algorithm and simulated anneal algorithm to optimize planetary gear reducer, and results showed that their optimal results were superior to genetic algorithm.

In the process of engineering design for gear reducer, there are a lot of unavoidable fuzzy information. To deal with the information by using conventional reliability design, there are greater conflicts between the design results and engineering practice even though analyzing many situations. To solve this problem, Jiang et al. [5] adopted fuzzy algorithm to deal with unavoidable factors and discussed theory and method of optimal fuzzy reliability design, which were validated with NSW planetary gear reducer. The results showed that the algorithm of optimal fuzzy reliability design expressed working situation of NSW planetary gear
reducer well and had economic benefits and practical value.

Real working situation of gear reducer is dynamic, so dynamic optimal design is important. For researching influence rule of floating bearing stiffness on dynamic-balance feature of planetary gear reducer power diffuence, with floating bearing stiffness as design variable, and minimal dynamic unbalance coefficient of power diffuence \( K_u \) and dynamic load coefficient \( K_d \) as optimal objective function, Yuan et al. [6] adopted genetic algorithm to do dynamic optimal design of planetary gear reducer.

For dynamic transmission error, with static transmission error or maximum amplitude of gear vibration as objective function, and modification of tooth profile as method, Marcello et al. [7] researched vibration of gear reducer by using non-linear dynamic model. By analyses of different physical conditions and torque levels, the optimal profile revised value of gear would be sought out within the control condition that can reduce the vibration of gear. The result showed that the algorithm was about same as Monte-Carlo method for reliability, and superior to the latter for efficiency.

Xu et al. [8] adopted Lagrange's equation of dissipation function to establish motion differential equation of system and to solve dynamic design result of gearing system by using Runge-Kutta method.

2.1.2 Multi-objective optimal design
Multi-objective optimization is more content with real situation of gear reducer design, so there are many literatures in this respect.

With fatigue strength reliability of gear and gear teeth matching as constraints, highest transmission efficiency, minimum weight and smallest volume as optimal objective, Sun et al. [9] combined optimal technology with reliability design theory, then established optimal mathematical model based on engineering practice and unified objective function method, finally adopted mixed-penalty function method and Powell method to optimize design of planetary gear reducer. The results showed that the algorithm has better optimization results based on reasonable working life.

Zhang et al. [10] discussed various factors of planetary gear reducer design, set up multiple-objective optimal model based on smallest volume and maximum contact ratio, and obtained the optimal solution by using multiplication and division method of multi-objective optimization and feasibility enumeration method.

With stress and strength as random variables, smallest volume and highest transmission efficiency as objective function, and reliability, fatigue strength, gear teeth matching and so on as constraint, Ye [11] established optimal model of two objective functions by using sequential quadratic programming method MATLAB optimal toolbox.

Xu et al. [12] applied the fuzzy reliability design theory in optimal design of planetary gear reducer, and established multi-objective function with smallest volume, minimum radial size, highest transmission efficiency, minimum temperature of bearings and so on. Finally, they adopted fuzzy decision and dispersing treatment method of mixed discrete variables with genetic algorithm to optimize design of gear reducer.

2.2 Static and dynamic working performance
In static and dynamic working performance of gear reducer, much research is focused on double-arc gear and planetary gear.

For static and dynamic working performance of arc gear, the best known is the research of Litvin et al. [13]. They researched profile, geometry, meshing, contact of arc gear, confirmed that contact path of gear surface and main contact direction of instantaneous contact ellipse, and analyzed transmission error caused by installing error.

Lu et al. [14] analyzed load distributions based on mismatch of gear surface and elastic transformation for double-arc gear, gained overlap coefficient of no installation error and installation error, and calculate stress by using I-DEAS software.

In Chinese, Wu et al. [15] established dynamic model involved some influences such as static transmission error, time meshing stiffness, damping, and so on. On this basis, influences of gear width, overlap coefficient and helical angle on dynamic process of double-arc gear were analyzed, influence rules of helical angle error and axis parallelism error on transmission error of double-arc gear were researched, and proposed calculate program of dynamic analysis for loading distribution conditions of double-arc gear contract path.

Zhang et al. [16] set up mathematic model of parameter optimization for double-arc gear profile by using three dimensional finite element method and fuzzy optimal design method.

Guo et al. [17] established solving equations of loading distribution based on angular displacement compensation principle, gained loading distribution between gear and contact path, and analyzed influences of install error on loading distribution.

Compared with general gear, the planetary gear has not only complicated structure and more quantitative components but also special motion way and over-constraint, so research difficulty of its dynamics is much larger.

For static and dynamic characteristic researches of planetary gear, most of they were restricted to linear scope, so the vibration damage of gear system would unavoidably happen. In particular, abnormal vibration in working often is cause of catastrophic
accident, linear theory is unable to explain this situation, and the analytical method of non-linear vibration must be adopted to analyze dynamic feature of power dividing transmission system.

Now, non-linear dynamic researches of gear are generally restricted for straight tooth cylindrical gearing, and non-linear dynamics researches of star class and planetary power dividing gearing system never quite achieved engineering demands.

For planetary gearing, meshing problem of many gears lead to more number of freedom and more complicated non-linear response feature. So, to research vibration mechanism and dynamic feature of time varying non-linear in gap and dynamic balance feature of loading distribution, which can improve power-weight ratio, prolong working life, reduce vibration and noise, and ensure working reliability, etc.

2.3 Fatigue-life prediction method

In considering unconventional working conditions, prediction research of fatigue life not only exactly confirm designed life of gear reducer but also do safety plan of unconventional working conditions ahead of time, and can reduce accident and working loss so that improve the level of workshop management.

Avinash [18] put forward a fatigue life analytical method of gear based on S-N curve in stages of crack initiation and diffusion. For the load test of different amplitude, their research show that fatigue-life of gear is easier to predict by using two-phase linear damage theory compared with Miner linear damage theory.

Kramberger et al. [19] indicated that ε-N theory of finite element method can be used to determine number of stress cycles in initial stage of fatigue crack.

Based on theory of linear-elastic fracture mechanics and finite element method, Aslantas et al. [20] researched pitting corrosion forming and fatigue-life prediction of straight gear considering of slide contact situation in gear rotary process.

In China, Li et al. [21] found best distribution types and possible distribution types of three random variables (ie life, strength and stress). Qi et al. [22] analyzed influence of slick-thickness ratio on fatigue-life of gear contact based on calculation of thermal elastohydrodynamic lubrication and experiment of roller fatigue, and their research results showed that increase of slick-thickness ratio can increase fatigue life of gear contact, but when which is over a certain critical value, fatigue-life is decreasing with increasing of slick-thickness ratio. For large complex structure system, Li et al. [23] adopt finite element method and life curve of material to calculate life value of main fatigue failure mode about large complex structure system. With the life value as sample value of maternal fatigue-life about structure system, one-sided tolerance factor method was adopted to predict structure system and to gain safe fatigue-life of certain confidence.

2.4 Oil sealing technology

Oil seal leakage is a difficult problem of reducer, the situation of which still will occur after a period of time even if oil seal is changed. Long term oil leakage will affect appearance of product and aggravate gear wear because of lack oil, which not only enhance use cost but also pollute environment. So, the research of oil sealing technology is hot in the world, and some achievements are gained.

So far, there appear many different schools for explanation of oil sealing theory. One is boundary lubrication theory, which states that the main reason of oil sealing by seal is a layer stable oil slick formed between lip and shaft interfaces.

The second main oil sealing reason is pumping effect modeling theory, which consider that surface tension of sealing oil will contribute to prevent leakage, and oil slick of contact area for sealing system is mixture lubrication state. In fact, oil sealing is achieved by pumping of oil seal that come from radial force and axial friction action between shaft and lip.

3. SUMMARY

In this paper, research results of gear reducer are introduced in optimal design technology, static and dynamic working performance, fatigue-life prediction method, and oil sealing technology. These research results illustrate that research technology of gear reducer is a complicated and extensive project.

To better design gear reducer, we ought to combine with principle and law of motion of gear meshing, static and dynamic working performance of gear, and optimal design. Based on above, design of overall transmission mechanism will be optimize, strength, deformation law, fatigue-life prediction and sealing of gear reducer will be researched.

This paper provide theory reference for designing gear reducer of smaller size, lighter weight, higher power, bigger speed ratio, and larger load.

REFERENCES


