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Multi-objective optimal design of cycloid speed reducer based on genetic algorithm

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ABSTRACT

The design of cycloid speed reducer has to satisfy various constraints, e.g. the geometrical, the kinematical and the mechanical, while delivering excellent performance, high efficiency, long life, great load capacity, etc. This invokes the need of an optimal design methodology to achieve these objectives collectively. Taking K-H-V cycloid speed reducers as the research subject, an optimization methodology based on genetic algorithm is presented. The goal of the optimization is to simultaneously minimize volume and maximize efficiency. The volume and the efficiency of the reducer are simultaneously taken as objective functions. The design variables including the short width coefficient, the diameter of the pin, the width of the cycloid gear, etc. are defined. The constraint conditions are established for multi-optimizations. In order to elaborate the proposed optimization methodology, the XW3-type cycloid speed reducer is chosen and utilized as an example for optimization. A comparison study on the single optimization is also carried out in this work. The research results are satisfactory and can help designers to employ for minimum material and cost by fulfilling high efficiency and other performance requirements.

1. Introduction

Cycloid speed reducers have found wide applications in the automation field as industry robots, machine tools, automatic machinery and other aspects owing to their excellent characteristics, e.g. high transmission accuracy, large reduction ratio, great load capacity, high efficiency, low backlash, long service life, high shock load capacity, etc. Therefore, the research and development of the cycloid speed reducers have been investigated by many researchers, including operating principle, conditions for non-undercutting manufacturing, force analysis and efficiency, and development of new mechanisms [1–6].

In general, the cycloid speed reducers can be classified into four types according to the lobe profile of the cycloid plate gear and the motion of the roller gear. They are the stationary ring gear type epicycloid reducers, the rotating ring gear type epicycloid reducers, the stationary ring gear type hypocycloid reducers and the rotating ring gear type hypocycloid reducers. But no matter what type it is, a cycloid speed reducer contains the transmission part, the input part and output part, etc. These components are interrelated and interact on each other, resulting that the running status and the output characteristics of the cycloid speed

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reducers will be influenced by one of the parameters of these components. For instance, the impact of a certain choice of gear width may yield a minimum mass gearing, but the selection of this gearing may cascade through subsequent steps of the design process (sizing of shafts, further stages, bearings, etc.) to ultimately lead to a heavier reducer. In addition, in the design of the cycloid speed reducer, designers always consider certain objectives such as efficiency, weight, load capacity, contact strength depending on the requirements. There also exist interactions and constraints between them, e.g., if module is calculated based on the objective of bending strength, the same module is substituted to calculate the objective of surface durability, it is accepted if it is within the strength limit of surface durability; otherwise it is changed accordingly. So optimization methods are required to determine design variables which simultaneously satisfy the given conditions. Moreover, increasing demand for compact, efficient, and reliable cycloid speed reducers forces the designer to use optimal design methodology.

There have been a number of studies attempting to optimize gears or gear reducers with the aid of computers. Thompson [7] presented a generalized approach to the minimum volume design of spur gear units based upon a traditional nonlinear programming. The methodology was applied to the design of two-stage and three-stage spur gear reduction units, subject to identical loading conditions and design criteria. Senthil Kumar [8] carried out the optimization of the asymmetric spur gear drive using an iterative procedure on the calculated maximum fillet stresses through FEM for different rack cutter shifts. The optimum values of rack cutter shifts were suggested for the given center distance and the speed ratio of an asymmetric gear drive. Tudose [9] discussed a two-stage helical gear transmission design problem (complete with the sizing and selection of shafts, bearings, housing, etc.) using a two-phase evolutionary algorithm in a formulation that can be extended to include additional stages or different layouts. Savsani [10] presented two advanced optimization algorithms known as particle swarm optimization (PSO) and simulated annealing (SA) to find the optimal combination of design parameters for minimum weight of a spur gear train. Buiga [11] carried out the complete automated optimal design with genetic algorithms of a two-stage helical coaxial speed reducer. The objective function (i.e. the mass of the entire speed reducer) was described by a set of 17 mixed design variables (i.e. integer, discrete and real) and also was subjected to 76 highly non-linear constraints. The results showed that the proposed genetic algorithm can offer better design solutions as compared with the results obtained by using the traditional design method. Tamboli [12] analyzed the helical gear pair for minimum volume using particle swarm optimization technique, since the most power transmission systems require low weight energy efficient and cost effective system elements. Wan [13] carried out the optimization of cycloid gears. The constraints were the cycloid gear can be mounted successfully at any place and the curve was without interference. The optimum objective was that the strength and stiffness of the pin gear housing weaken was least serves. Wang [14] proposed a new method to determine the dynamic model of a practical gear system by the identification of the relation between the rotational movement of gears and the acoustical noise signal measured on the gear tester. The optimized gear tooth profile modification was derived based on the identified model. The tested result showed that the profile modification can greatly reduce gear noise. Li [15] analyzed the realization of the generalized reduced gradient method and its application in a single-stage cylindrical gear reducer design. The experimental results showed that the proposed method has fewer iterations and higher precision. He [16] carried out an optimal design method to reduce vibration and noise of double crank ring-plate-type pin-cycloid planetary drive. Zhang [17] established an optimization model, which included discrete variables (module), integer variables (teeth number) and continuous variables (tooth width, spiral angle, etc.), and proposed a new optimization solution algorithm to obtain the discrete solution of module and teeth number.

An engineering design optimization problem is generally composed of multiple objectives, associated with a constrained parameter space, thereby getting the name as (constraint) multi-objective optimization. Formally, the multi-objective optimization refers to the solution of problems with two or more objective functions, which are normally in conflict with each other. Nowadays, only a few references can be found on multi-objective optimal design of reducers. Gao [18] carried out the multi-objective optimizations of the harmonic reducer. On the basis of the optimization results, a new type short cylindrical cup-shaped harmonic reducer was designed and manufactured. Wang [19] established a multi-objective optimization model of optimizing contact force and reducer volume in order to reduce the gearbox volume and the impact of running while improving bearing capacity. Wang [20] presented a multi-objective optimization design method for helical gear reducer based on simulated annealing algorithms. The simulation experiment indicated that the optimal result was superior to that of traditional design scheme. Zhang [21] constructed an optimization model for planetary gear reducer in shield tunneling machine with four objective functions, that was to make its volume smallest, its efficiency highest and the reliability of its contacting and bending strength highest, which were subject to the conditions such as teeth, modification coefficient, interference, strength, equal strength and equal life. In order to reduce the gearbox volume and the impact of running while improving bearing capacity, Wang [22] established a multi-objective optimization model, in which five reducer dimensions were selected as the design variables to construct eight nonlinear constraint equations.

These studies referenced above have been instrumented in order to highlight two important aspects regarding the topic of this work. Firstly, it is obvious that most of the references cited above applied the optimization techniques for individual components (only gears or shafts) or intermediate assemblies rather than to the entire speed reducer (considering the multiple connections between its subsystems, i.e. the gearings, the shafts-subassembly, and the housing). Secondly, only a few references focus on multi-objective optimal design of reducers, especially on cycloid speed reducers. The aim of this work is to establish a multi-objective optimization model of optimizing volume and efficiency of K-H-V cycloid speed reducers. A comparison study on single-objective optimization of cycloid speed reducers, whose objective function is volume and efficiency, respectively, is also carried out in this work.