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Research paper

Prediction and optimization of hobbing gear geometric deviations

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ABSTRACT

Hobbing is a precision gear manufacturing process with high efficiency and low cost. High precision gears are essential components for high-end equipment to meet the requirement of extreme operation conditions. In order to further improve the precision of gear hobbing process as well as lower the gear manufacturing cost, this paper proposes a model for predicting the hobbing gear geometric deviations and optimizing the hobbing processing technique. The relationship between gear hobbing processing technique and gear geometric deviation is modeled applying the improved Particle Swarm Optimization and Back Propagation algorithm. The performance of the proposed method is compared with the existing optimization and back propagation method and validated by experiments. The accuracy of both algorithms is evaluated by the Root Mean Square Error between the predicted and experimental values. The result shows that the gear geometric deviations predicted by the proposed algorithm yields better performance and are in reasonably good agreement with experimental data. Employing the proposed model, the gear hobbing process parameters can be optimized to minimize gear geometric errors, and thus improve the gear manufacturing precision.

1. Introduction

High precision gears are crucial components that determine the performance, service life, safety and reliability of high-end equipment. Today, a common process to manufacture a precision gear mainly includes two steps: gear hobbing as a semi-finishing process and gear grinding as a finishing process. According to Dudley [1], Michalec [2] and Lynwander [3], hobbing is a versatile and economical process for cutting gear teeth. Generally, when compared with the grinding process, the hobbing process has the advantage of high efficiency and low cost. Meanwhile, it has the disadvantage of relatively low accuracy. If the accuracy of the hobbing process can be improved to satisfy the requirement for certain gear, for example, the fine pitch gears such as automotive steering pinion and gears used in small reduction gear box, the improvement of the gear hobbing precision is quite meaningful as it can partly replace the following grinding process or at least improve the accuracy of the pre-grinding gear, which will enhance the efficiency of gear manufacturing. In order to further improve the precision of hobbing gear, the mapping relationship between gear geometric deviations and its influencing factors should be

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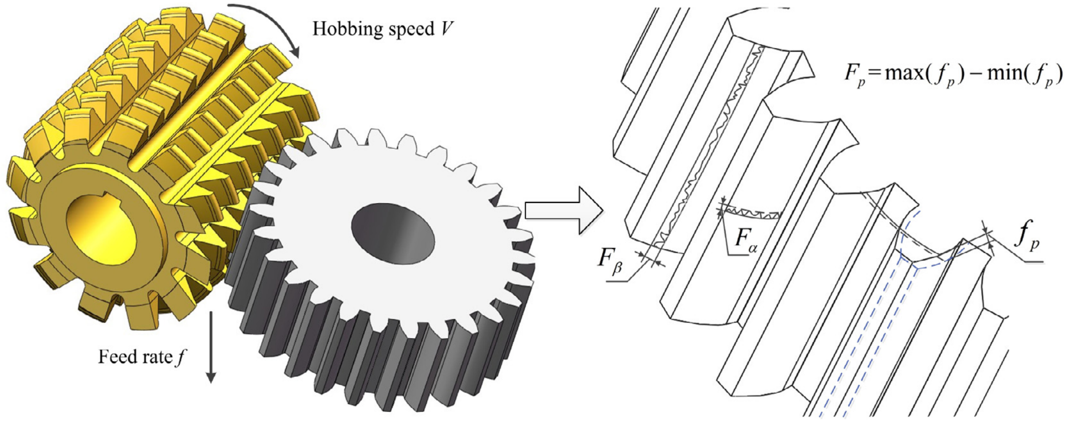

Fig. 1. The sketch of processing parameters and gear geometric deviations.

investigated. In general, there are three main factors that affect the precision of hobbed gears: hob cutter, hobbing machine tool and hobbing processing technique.

Various researchers have made the efforts to improve the gear hobbing manufacturing precision by studying these three factors. Regarding the hob cutter geometry, Hsu [4] proposed a mathematical model of the modified hob with variable tooth thickness. Klocke et al. [5] simulated the effect of deviations of hob cutter and clamping on gear profile deviation and lead deviation in the hobbing process. Wang [6] established the mapping rules between hob geometric errors and gear geometric precision. Chiu [7] proposed a method to improve the tooth profile accuracy of hobbed gears by optimizing hob eccentricity. Radzevich [8] developed a novel design of precision gear hob for machining precision involute gear. Regarding the machine tool setting, Michalski [9] presented an analysis of surface topography of tooth space flanks of cylindrical gear machined after hobbing and chiseling by Fellows method. Bouzakis [10] presented an experimentally verified computational procedure to determine the optimum values for the shift displacement and for the corresponding shift amount, by considering the wear behavior of the hob teeth in the individual generating positions. With regard to the processing technique, Jiang [11] proposed a generic gear mathematical model simulating the generation process of a 6-axis CNC hobbing machine. Brecher [12] proposed a new formula to calculate the maximum chip thickness in the hobbing process considering the effect of workpiece, tool and process parameters. Cao et al. [13] studied the decision making of process parameters in gear hobbing process with back propagation neural network/ differential evolution method. Chandra [14] proposed a new method which not only promotes the machining quality of workpiece but also improves the processing technique significantly. Bouzakis [15] proposed a methodology for predicting tool wear and simulating gear hobbing cutting process. Vedmar [16] applied parametric and analytically differentiable functions to determine the geometry of the three-dimensional surface of the hobbed gear. Sari [17] investigated the wear behavior of gear finish hobbing using several cutting materials.

Generally, it is difficult to achieve the optimization of hob profile and the compensation of hobbing machine's axis error, because it involves additional measurement equipment and hob profile modification. In contrast, it is easier to improve the gear hobbing technique by modifying the CNC codes and selecting appropriate processing parameters. In the past, the researches of gear hobbing technique generally focus on the modeling and simulation of chip thickness and wear behavior of hobbed gears, few studies can be found in the open literature to illustrate the prediction of gear geometric deviations and optimization of processing parameters to obtain more precise hobbed gears. The gear geometric deviations include the total deviation of the tooth profile (F_α), the total helical deviation of the tooth surface (F_β) , the single pitch deviation (f_p) and the accumulated pitch deviation (F_p) of the tooth surface. These gear geometric errors can determine the transmission accuracy and noise level. Therefore, it is necessary to reduce the gear geometric deviations for the better performance of geared transmission system. Among all the methods for improving the gear precision, the optimization of the gear hobbing processing parameters, such as cutting speed (V) and feed rate (f), is the easiest to be implemented. The sketch of processing parameters and gear geometric deviations are shown in Fig. 1. However, due to the complicated, non-linear and stochastic process mechanism in gear manufacturing, the generalized relationship between the gear geometric deviations and hobbing processing parameters is hard to be formulated accurately. Neural networks are usually suitable for this case in which the explicit mathematical expression is unavailable. Therefore, this paper proposes a neural network algorithm based on improved Particle Swarm Optimization (PSO) and Back Propagation (BP) method to predict the geometric deviations of hobbed gears and optimize the processing parameters to obtain more precise gears.

The Back Propagation (BP) algorithm is applied to predict the gear precision due to its strong fitness to non-linear characteristics. The BP algorithm has been used in various fields. Ojha et al. [18] used the BP neural network to predict the maximum, minimum and most proximate estimates of the tool life. Liu et al. [19] used the BP neural network to reveal the relationship between the bending radius and the affecting factors. However, BP algorithm has some drawbacks such as local optimum, slow convergence and low generalization capability. To avoid these drawbacks, the improved Particle Swarm Opti-