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Research paper

A novel gear flank modification methodology on internal gearing power honing gear machine

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ABSTRACT

In order to reduce the impact of load fluctuation, noise and vibration, the tooth surface of the gear in the high speed transmission gearbox is usually modified along the lead and profile direction. In this paper, a method for lead and profile crowning tooth flank of work gear is proposed by setting the movement of A and B axes as two fourth order polynomial functions of axial feed of work gear in the internal gearing power honing. Diamond dressing gear used for honing stone in dressing process is standard involute, and it is not necessary to design an especial diamond dressing gear for each different modified gear. The sensitivity matrix of polynomial coefficients is calculated by the normal deviation of the gear tooth surface, and the influence of the variation of polynomial coefficients on the tooth surface is studied. The honed tooth surface can be approximated to the given tooth surface by adjusting the polynomial coefficients through least squares estimation with the aim of minimization of the tooth surface errors based on sensitivity matrix. The effectiveness of this crowning tooth flank modification method is confirmed numerically using a helical gear on the internal gearing power honing machine.

1. Introduction

Accompanying with the rapid development of manufacturing, the requirements of the machining accuracy and surface quality of the gear are constantly improving. Almost all of the high speed gears have to be modified to meet the requirements of low noise and high strength. As a highly efficient and economical finishing process of hardened gears, honing has a great advantage in eliminating the deformation of the gear after heat treatment. In gear honing process, it can be divided into internal gearing honing gear and external gearing honing gear according to the meshing method of work gear and cutting tool. In practical application, internal gearing honing gear is frequently used due to stronger tooth surface error correction function and higher overlap factor. The cutters used in the dressing process and the honing process are diamond dressing gear and honing stone, respectively. In recent studies, the research on gear honing are mainly focused on the generating machining, honing speed, surface trajectory, and honing process parameter optimization. Study on crowning modification of gear honing is mainly based on a crowning diamond dressing gear and a method of setting a crossed angle between the honing stone and work gear axes as a linear function of work gear's axial feed. However, this method requires the design of a crowning diamond dressing gear for different modified tooth surfaces, increasing the gear manufacturing cycle. Hence this paper proposes a tooth flank crowning method for helical gears by setting the movement of A and B axes as two fourth order polynomial functions of axial feed of work gear without the need to crown diamond dressing gear.

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Nomenclature

ϕ_d	rotation angle of the dressing tool in dressing process
ϕ_h	rotation angle of the honing stone in dressing process
u_d,θ_d	surface parameters of standard involute helical surface of dressing tool
r_{bd}	radius of the base cylinder of dressing tool
σ_{0d}	starting angle of involute helical surface of dressing tool
p_d	helix parameter of involute helical surface of dressing tool
Σ_{hd}	crossed angle between the honing stone and dressing tool
E_{hd}	operating center distance between the honing stone and dressing tool
N_h	the number of teeth of the honing stone
N_d	the number of teeth of the dressing tool
N_g	the number of teeth of the work gear
F_{z1}	axial feed along the axis of gear in honing process
ϕ_A	rotation angle of honing stone head for axis crossing angle in honing process
ϕ_B	rotation angle of honing stone head for longitudinal crowning and tapering in honing process
ϕ_{C1}	rotation angle of honing stone in honing process
ϕ_{C2}	rotation angle of work gear in honing process
E_{gh}	operating center distance between the work gear and honing stone
E_B	center distance between the honing stone and B axis
β_g	helix angle of the work gear
r_{pg}	pitch circle radius of the work gear
b_g	face width of work gear
Σ_{gh}	crossed angle between the honing stone and the work gear
β_h	helix angle of the honing stone

Twisted tooth phenomenon on helical gears caused by the application of conventional radial crowning methods in gear finishing process has been explained by Lange [1], who also brought forward a measure to avoid this bias error. Litvin et al. [2] and Dudley [3] made a detailed analysis of the gear meshing principle, gear machining and tooth contact analysis in their textbook. Fong et al. [4] proposed a new technique for tooth surface crowning of helical gears, which uses alterable lead grinding worm and diagonal feed motion, and the radial feed is formulated as a fourth order polynomial function of axial feed. Shih et al. [5,6] built a tooth flank correction technique on a five-axis CNC gear profile grinding machine, each axis of which is expressed as a six-degree polynomial of rotation angle of the work gear during the grinding process and the wheel profile is represented by B-spline curves with a normal correction function. Jiang et al. [7] proposed a methodology of tooth flank modification for cylindrical gears that possess a controllable higher order polynomial function of transmission error to restrain vibrancy and noise. Then Jiang et al. [8] presented a method for profile and lead crowning tooth flank of helical gears on a six-axis CNC hob machine by setting each axis as a high-order polynomial function of axial feed of work gear and rotational motion of hob. In order to eliminate the tooth surface distortion caused by the traditional hobbing modification method, Hsu et al. [9] proposed a method using variable tooth thickness hob and diagonal feed to diminish the tooth surface twisting of lead crowning gear. Tran et al. presented a method for machining helical gears with longitudinal tooth crowning by attaching a nonlinear function in terms of the hob's rotation angle and the traverse movement of work gear to the rotation of work gear during hobbing process [10], then the hob's diagonal feed motion is set as a second order function of hob's traverse movement and tooth profile of hob cutter is modified in a dual-lead form with pressure angle changed in its longitudinal direction [11]. Subsequently, a method for longitudinal crowning tooth flank of work gear was proposed by setting a crossed angle between the honing cutter and work gear axes as a linear function of work gear's traverse feed and a variable pressure angle (VPA) honing cutter is also used for free twist of the crowned tooth flank in the external honing process [12–14]. To improve the production efficiency of the face gear, Wang et al. [15] studied a honing method for face gear with tooth profile modification and proposes a face gear honing principle. Wang et al. [16] used the diamond dressing gear with the same tooth surface as the work gear tooth surface to repair the honing stone to obtain the target tooth surface in the external honing process. Based on the gear meshing principle, Liang et al. [17] established the kinematic model of the relative sliding velocity at the contact point between the work gear and the honing stone. On this basis, the contact line equation and the acceleration equation at the contact point were deduced. In order to concentrate and stabilize the contact area, so as to reduce the noise and vibration, Litvin et al. [18,19] proposed a tooth surface modification method using a profile crowned shaver and a variation of shortest distance between the shaver and pinion axes in shaving process.

Draw on the experience of this above researches, it can be seen that a host of tooth surface modification method is to use the modified cutter to process the modified gear. In this way, different cutters are needed for different modified gears, which undoubtedly increases the cutter cost and prolongs the development cycle. In order to quickly process the required modified gears in the research phase, and not to make special trimming cutters, this paper only uses the axes which existed in the CNC machine tools to process the modified gears.