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Roughness model for tooth surfaces of spiral bevel gears under grinding

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ABSTRACT

A mathematical model of grinding roughness for spiral bevel gears is proposed. The model considers two sources that contribute to the roughness, (i) material removal, and (ii) the discretized generating movement between the grinding wheel and the workpiece. For source (i), the classical roughness model for general orthogonal grinding is adopted, for which the grinding process of spiral bevel gears is reviewed in a new framework to extract necessary parameters. With the proposed model, roughness can be calculated as a distribution over the gear surface. An example is presented to show the process, based on which several measures to optimize the grinding parameters are discussed.

1. Introduction

Grinding is an important part of the machining process for gears. It's usually the last procedure, to correct the tooth profiles that have been dislocated by heat treatment. Grinding helps to improve accuracy of the tooth profiles, as well as reduce its roughness. Roughness, as the subject of this paper, has a great influence on the distribution of contact pressure on tooth surfaces under meshing, hence affects the fatigue life significantly.

More specifically, discussed in this paper is the roughness of spiral bevel gears ground on SGM. The grinding wheel follows the shape of a generating gear that is supposed to engage with the machined gear. So the general orthogonal grinding mechanism and the generating principle of the spiral bevel gear need to be investigated from the very bottom to build up a mathematically sophisticated roughness model.

In researches of the general grinding mechanism, the abrasive sliding length per unit volume of material removal was found to be the main factor affecting the surface roughness [1]. Various assumptions and different approaches have been proposed to predict the roughness of the grinded surface. Using an analytical method, Ono Koji [2] built the classical theory of grinding mechanism based on the concept of subsequent grinding edge, which assumed that grinded surfaces were generated alone with the material removal process, while the effect of plastic deformation and material extrusion being neglected. This assumption led to an underestimated theoretical value of roughness. To overcome this shortcoming, the effects of plastic upheaval were investigated in subsequent researches [3,4]. Xiu et al. analyzed how the upheaval deformation affected the maximum depth of the valley of a roughness profile and gave the plastic coefficients and modified the roughness formula [5]. Then the random distribution of

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the grain protrusion heights on the grinding wheel surface was taken into consideration, and a truncated Gaussian distribution model was developed to relate the wheel volume wear to the change in the mean value of the protrusion heights [6,7].

In terms of gear grinding, most of the researches focused on the effects of heat, while the researches on the grinding roughness, especially for spiral bevel gears, are rare. By using non-uniform velocity generation technique, the theoretical surface roughness can be made uniform everywhere on a cylindrical gear surface [8]. Kong et al. [9] derived the motion path equation for the abrasive on the grinding wheel, assuming a statistical model for the abrasive particles, based on which the grinded surface of a spiral bevel gear was constructed. Yang et al. [10] took the tooth surface roughness forecasting as a gray system, and applied an optimization method to derive a roughness model. Ming et al. [11] discussed the height of the residue area caused by the NC machine, and transformed it from the three dimensional space into a two dimensional plane. Along with the plastic upheaval, this 2D height of the residue area was considered in the same roughness model.

In this paper, a mathematical model of the surface roughness was derived for spiral bevel gears machined by the face milling method, and the distribution of roughness on tooth surface could be derived.

The model considered both the material removal caused by the complex movement during grinding and the discretization effect of the NC machine. For the effect of material removal, the theory of general orthogonal grinding roughness was adopted, of which the parameters were derived by reformulating the machining principle of spiral bevel gears, through a coordinate system mapping method. For the influence of the discretized movement of the NC machine, a procedure is proposed to quantify the maximum height of the uncut zone.

An example case then is demonstrated, and the results of calculation and ways to improve the grinding process are discussed.

Nomenclature

$\dot{\boldsymbol{q}}_2$ angular velocity of the revolution of grinding wheel (rad/min)
X_{B2}, E_{D2} and X_2 basic parameters of machine tool (mm)
$\omega_{M'M}$ relative angular velocity between the grinding wheel and the gear (rad/min)
H_1 maximum height of contour for spiral bevel gears reflecting the effects of 'cutting' and 'plow'
H_2 maximum height of the uncut zone
H_{Ono} maximum height of contour in the vertical direction of grinded surface calculated by Ono Koji (mm)
M_0' tip apex
O_2 intersection point of axes of the ring gear and its meshing pinion
R_a roughness (μm)
S microstructure Group number of grinding wheel
S_2 radial distance (mm)
W_2 point width (mm)
i_{02} transmission ratio
$\boldsymbol{i}\_\boldsymbol{j}$ plane machine tool plane
r_0 average cutter radius (mm)
r_{02} cutter point radius of the grinding wheel (mm)
s_2 length of $\boldsymbol{M}'\boldsymbol{M}_0'$ (mm)
$\boldsymbol{m}_2$ vector pointing from O to O_2
$\boldsymbol{n}_2$ unit normal on the grinding wheel cone at M_0
$\boldsymbol{q}_2$ center roll position (°)
$\boldsymbol{r}_{O'A'}$ vector pointing from O' to A'
$\boldsymbol{r}_{O_2A}$ vector pointing from O_2 to A in system $\boldsymbol{\sigma}$
$\boldsymbol{r}_{OO'}$ vector pointing from O to O'
$\boldsymbol{r}_{gr}$ the grinding tangent
$\boldsymbol{t}_2$ unit tangent on the grinding wheel cone at M_0
$\boldsymbol{v}_{A'\sigma'}$ velocity of A' in the system $\boldsymbol{\sigma}'$
$\boldsymbol{v}_{A'gr}$ projection of $\boldsymbol{v}_{A'\sigma}$ onto the direction of $\boldsymbol{r}_{gr}$
$\boldsymbol{v}_{A'\sigma}$ velocity of A' in the system $\boldsymbol{\sigma}$
$\boldsymbol{v}_{O'\sigma}$ velocity of the wheel center in the system $\boldsymbol{\sigma}$
$\boldsymbol{v}_{Agr}$ projection of $\boldsymbol{v}_{A\sigma}$ onto the direction of $\boldsymbol{r}_{gr}$
$\boldsymbol{v}_{A\sigma}$ overall velocity of A in system $\boldsymbol{\sigma}$
α_{02} blade angle
α_b relative chip volume
δ_{M2} root angle of the gear(°)
θ_2 phase angle of both M' and M_0'(°)
θ half of the cone angle (°)
$\boldsymbol{\sigma}_2\{O_2; \boldsymbol{i}_2, \boldsymbol{j}_2, \boldsymbol{k}_2\}$ Cartesian coordinate system set for the workpiece
$\boldsymbol{\sigma}_{2f}\{O_{2f}; \boldsymbol{i}_{2f}, \boldsymbol{j}_{2f}\}$ coordinate system on axial section plane of the gear (Fig. 4)