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Meshing simulations of the worm gear cut by a straight-edged flyblade and the ZK-type worm with a non-90° crossing angle

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Abstract

The contact analysis of the worm gear set with a non-90° crossing angle is investigated in this research. The worm gear set is composed of the ZK-type worm ground by a grinding wheel and the worm gear generated by a straight-edged flyblade. This worm gear set with a non-90° crossing angle provides higher contact ratio compared to those with 90° crossing angle. The mathematical model is derived and the meshing simulations are performed to examine the transmission errors, contact ratios and contact ellipses of this worm gear sets with non-90° crossing angles. The simulation results reflect the special contact nature of this type of gearing.

Keywords: Worm; Worm gear; Flyblade; Tooth contact analysis

1. Introduction

The worm gear set is composed of a worm and worm gear, and is one of the most important devices for transmitting torque between spatial crossed axes. Due to its high transmission ratio, steady working situation and compact structure, worm gear set is widely used in gear reduction. The mathematical model and contact analysis of worm gear sets have been studied by many researchers in these years. Their efforts improved the efficiency and working life time of worm gear sets. Wildhaber [1] was the first to use the surface curvatures to obtain an approximate tooth contact bearing diagram for worm gears cut by oversize hob cutters. Winter and Wilkesmann [2], Simon [3] and Bosch [4] proposed different methods of obtaining more precise worm surfaces.

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Fig. 1. Worm gear set with a non-90° crossing angle.

Phillips [5] proposed the kinematics of skew gearing according to screw theory. Kin [6] investigated the limitation of worms to avoid undercutting, and also studied the envelope existence of contact lines. Colbourne [7] investigated undercutting, interference and non-conjugate contact of the ZK-type worm gear set. Janninck [8] proposed a method for predicting the initial contact pattern and showed their results by applying a surface separation topological diagram over the entire worm gear surface. Colbourne [9] proposed a method for designing oversize hob cutters to cut worm gears. The contact surface separation topology concept was also adopted to show the results of his design. Litvin and Kin [10] also proposed a generalized tooth contact analysis (TCA) algorithm to determine the position of transfer points where an ideal contact line will turn into a real contact point. Kin [11] studied the surface deviations of the produced worm gear tooth surfaces due to cutting-edge deviations of hob cutters. Otherwise, Tsay et al. [12–17] proposed the mathematical models, bearing contact, transmission error (TE) and contact ratio (CR) of ZK, ZN and ZE-type worm gear set with various tooth profile modifications to investigate the effects on the meshing of worm gear sets.

Although the previous studies have significantly improved understanding of the characteristics of worm gear sets, they largely focused on analyses of worm gear sets with 90° crossing angle. As shown in Fig. 1, the worm gear set in this research meshes with a non-90° crossing angle. This worm gear set provides higher CR compared to conventional worm gear set with 90° crossing angle. This gear set is composed of the ZK-type worm ground by a grinding wheel and the worm gear cut by a straight-edged flyblade. According to the developed mathematical model, the meshing simulations are performed to examine the TEs, CRs and contact ellipses of the worm gear sets with non-90° crossing angles.

2. Mathematical model of the ZK-type worm

In this study, the worm is the single enveloping ZK-type worm which is generated by a grinding wheel. As illustrated in Fig. 2, the grinding wheel is inclined with an angle the same as the worm helix angle.

2.1. Mathematical model of the grinding wheel

Fig. 3 illustrates the right-side and left-side surfaces of the grinding wheel, which generate the left-side and right-side tooth surface of the ZK-type worm, respectively. The position vector and unit normal vector of the grinding wheel surface can be represented in coordinate system $\mathbf{S}_c$ as follows:

$$\mathbf{R}_c = \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = \begin{bmatrix} u_1 \cos\alpha_n \cos\theta \\ u_1 \cos\alpha_n \sin\theta \\ \pm(b_l - u_1 \sin\alpha_n) \end{bmatrix} \tag{1}$$