Mechanism and Machine Theory 113 (2017) 40–52

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Research paper

Tooth contact analysis of crossed beveloid gear transmission with parabolic modification

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ARTICLE INFO

Article history:
Received 12 September 2016
Revised 12 February 2017
Accepted 9 March 2017

Keywords:
Beveloid gear
Parabolic modification
Crossed axes
Tooth contact analysis
Misalignments sensitivity

ABSTRACT

Considering the gear manufacturing and meshing theory, a numerical design approach with parabolic modifications was proposed to improve the mesh behaviors of crossed beveloid gear transmission. The generating procedure with parabolic modifications for the crossed beveloid gears with small shaft angle was proposed. And the analytical mesh model with misalignments of crossed beveloid gear transmission was developed. Then the effects of parabolic modifications on contact path and contact ratio were investigated. Also, the misalignments sensitivity was analyzed for the beveloid gears with and without parabolic modifications. Results show that the design situation with a positive parabola coefficient for the pinion and a negative parabola coefficient for the gear is better than other combinations of the parabola coefficients. Both the offset error and shaft angle error tend to deviate the contact path from the theoretical middle region. The parabolic modifications can reduce the sensitivity of contact path to the offset error and shaft angle error for crossed beveloid gear transmission effectively. Both axial pinion and gear position error has little influence on the mesh behaviors for the crossed beveloid gear pair with and without parabolic modifications.

1. Introduction

Beveloid gear which can realize the spatial transmission with small shaft angles is widely used in the fields of speedboat [1], all-wheel drive vehicles [2], radar tracking system and aviation precision machinery. It has many advantages including small volume, compact structure, high precision, easy manufacturing and low cost. However, it is theoretical point contact for the engagement and the higher resulted high sliding speed between beveloid gears can produce the early wear of gear tooth, which leads to the low bearing capacity of tooth surface and short service life.

Recently, lots of research has been performed on the geometry design and tooth contact analysis of beveloid gears. Tsai and Wu [3,4] discussed the geometry design method of beveloid gears and conducted the loaded tooth contact analysis (LTCA) of skew conical involute gear pair in approximate line contact. Brecher et al. [5] developed two methods to calculate the tooth load carrying capacity of beveloid gears with parallel axes. Eberhard et al. [6,7] developed a mesh model with the fully elastic multibody and investigated the effects of standard and non-standard tooth profiles on the contact characteristics of beveloid gears considering deformations. Liu et al. [8,9] presented two mathematical models of concave beveloid gears and performed the contact analysis of concave beveloid gear pair to investigate the contact behaviors of concave conical involute gear pair with non-parallel axes. Li et al [10] developed a new way to calculate the profile and axial errors of

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http://dx.doi.org/10.1016/j.mechmachtheory.2017.03.004

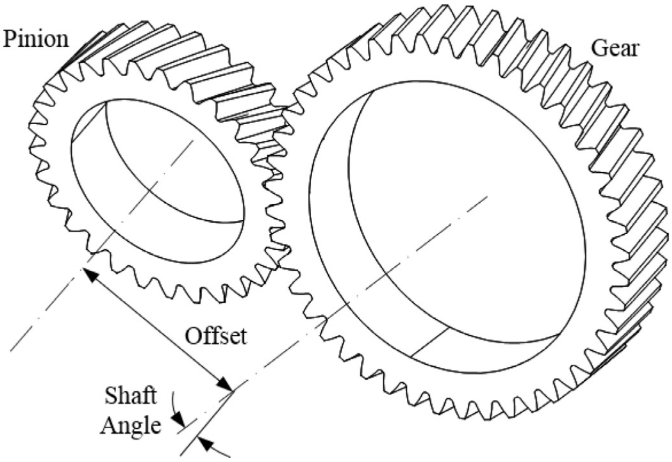

Fig. 1. Crossed beveloid gear transmission.

noninvolute beveloid gears. Zhu et al. [11,12] investigated the approximate line contact condition by controlling the angle between the first principal directions and analyzed the effects of the design parameters, load and misalignments on the mesh for crossed and intersected beveloid gears with small shaft angle. Brecher et al [13,14] simulated the manufacturing of beveloid gears and investigated the effect of manufacturing methods on the running behavior of beveloid gears. Brauer [15,16] derived the mathematical model of conical involute gears and researched the transmission error of anti-backlash conical involute gear transmission using a global-local finite element method. For the parabolic modification, Oswald et al. [17] discussed the effect of parabolic profile modification on the dynamic response of low-contact-ratio spur gears. Zhang et al. [18] modified the line segment of rack cutter into parabolic and investigated the effects of parabolic modifications on the transmission error and load distribution of helix gear transmission. Litvin [19] used the rack cutter with parabolic profile to generate the profile-crowned helical gear and analyzed the contact characteristics. However, the research studies mentioned above are mainly focused on geometric design and contact analysis of beveloid gears or parabolic modification on spur or helix gear, little discussed the effects of parabolic modifications on beveloid gear pair transmission with crossed axes.

In this paper, the generating procedure with parabolic modifications for the crossed beveloid gears with small shaft angle was proposed. And the analytical mesh model with misalignments of crossed beveloid gear transmission was developed. Then the effects of parabolic modifications on contact path and contact ratio was investigated. Also, the misalignments sensitivity was analyzed for the crossed beveloid gear pair with and without parabolic modifications.

2. Beveloid gear tooth profile with parabolic modification

Crossed beveloid gear pair is usually used to transmit motion and power with a small shaft angle which is less than 20° and the transmission diagram is shown in Fig. 1, the shortest distance of axials of two beveloid gears is defined as offset, and the angle between two axials is called shaft angle. Beveloid gear can be manufactured by conventional hobbing method, based on the generation concept of beveloid gear proposed by Mitome [20], the generation process of beveloid gear can be consider as the envelope process of rack cutter. The normal section of the rack cutter with parabolic modification is shown in Fig. 2. Without parabolic modification, the common normal section mainly consists of the straight edges and the fillet curves. In the figure, the previous rack cutter with straight lines is represented using the dashed line and the proposed rack cutter with parabolic modification is represented using the solid line. Three coordinates are created for the normal section and the origin of S_n is located to the middle point of tooth space on the standard pitch line of rack cutter. The origins of S_{al} and S_{ar} are located to the apex of the parabola at the left side and the right side, respectively. X_{al} and X_{ar} are tangent to the parabola. a_j is the parabola coefficient that can determine the amount of profile modification. l_j ($j=1$ for the pinion, $j=2$ for the gear) is the surface parameter of rack cutter. S_0 is the normal space width which is equal to $\pi m_n/2$. a_n is the normal pressure angle.

The coordinates of the points on the parabola can be represented in the coordinate system S_{ar} by

$$R_{ar}^{j} = \begin{bmatrix} x_{ar}^{j} \\ y_{ar}^{j} \\ z_{ar}^{j} \end{bmatrix} = \begin{bmatrix} l_j \\ a_j l_j^2 \\ 0 \end{bmatrix} \qquad (j = 1, 2) \tag{1}$$