Mechanism and Machine Theory 71 (2014) 40–51

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Tooth contact analysis for helical gear pairs generated by a modified hob with variable tooth thickness

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ARTICLE INFO

Article history:
Received 24 May 2013
Received in revised form 24 August 2013
Accepted 2 September 2013
Available online 28 September 2013

Keywords:
Gear hobbing
Variable tooth thickness hob
Tooth contact analysis
Contact ellipse
Transmission error

ABSTRACT

Conventionally, the longitudinal crowning of helical gears can be accomplished by varying the center distance between the hob and work gear in gear hobbing process. Without a crossed angle compensation, however, this center distance variation produces twisted tooth flanks on the work gear. A methodology is thus proposed herein to reduce the tooth flank twisting of a longitudinal crowning gear by applying a modified variable tooth thickness hob and having a diagonal feed without varying the center distance. This study also investigates the gear tooth surface topologies, contact ellipses and transmission errors of the work gear pairs, generated by a conventional hob and the proposed modified hob with variable tooth thickness, respectively. Three numeral examples are presented to illustrate and verify the merits of the proposed gear hobbing method with longitudinal crowning.

1. Introduction

In gear hobbing, one of the most efficient and economical methods to produce cylindrical gears is to generate the work gear by setting a hob with a work gear on the crossed axis in a way similar to that of the meshing of crossed helical gear sets. The conventional longitudinal crowning of a work gear tooth flank is usually done by varying the center distance between the hob and work gear, while treating the crossed angle between the hob and work gear as a fixed machine-tool setting, during the hobbing process. Without a crossed angle compensation, however, this center distance variation produces a twisted tooth flank on the work gear, which in turn induces a bias tooth wear and a higher level of noise. Therefore, this study proposes a methodology for substantially reducing the tooth flank twist problem in longitudinal crowning by modifying the hob's tooth thickness and having a hob's diagonal feed without varying the center distance.

The basic meshing conditions of a crossed helical gear set have been derived in some textbooks [1], and extensive qualitative discussions on the hobbing process are available in the publication of Liebherr-Verzahntechnik GmbH [2]. In addition, Bouzakis and Antoniadis [3] proposed a methodology for determination of the best diagonal shift amount in gear hobbing, while Chen [4] and Chen and Fong [5] developed a mathematical model with a two-parameter equation of meshing for simulation of the hobbing process. Meanwhile, Fette GmbH and Liebherr-Verzahntechnik GmbH[6] patented a method for reducing the natural twist of the work gear tooth flank by varying the hob's profile angle along its lead and shifting the hob diagonally over the whole tooth face width during gear hobbing. However, the above-mentioned hob profile angle's change requires a special angular motion on the grinding wheel which is not available on the commercial gear grinder. Besides, Fuhua and Chuang [7] patented a double-lead finishing hob for the finishing cut of one side of the gear. Recently, Hsu and Fong [8] proposed the design of a variable tooth thickness (VTT) hob in its longitudinal direction and a method of gear hobbing with a diagonal feed and without varying the center distance. Besides, Litvin et al. [9,10] proposed a generation mechanism with a five-degree-of-freedom system, together

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0094-114X/$ – see front matter
http://dx.doi.org/10.1016/j.mechmachtheory.2013.09.001

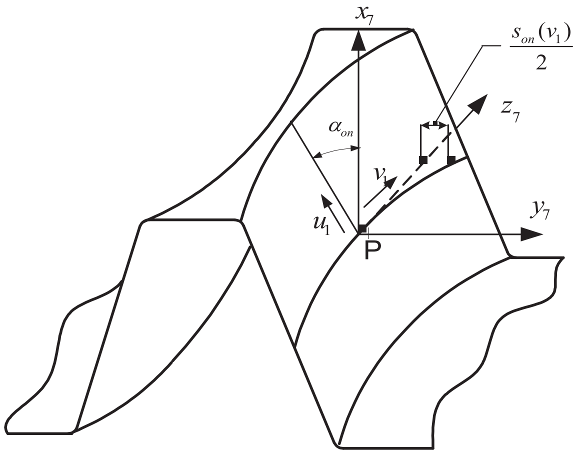

Fig. 1. Surface parameters of the VTT rack cutter.

with tooth contact analysis (TCA) that prevents the gear edge contact and a geometric modification of spur gears that reduces transmission errors. Litvin and Kim [11] used this modified geometry to investigate the simulation of meshing and contact of misaligned spur gears. Litvin, et al. [12] then proposed an asymmetric spur gear drive that enables the localization and stabilization of the bearing contact and obtains a favorable shape of transmission errors with a reduced magnitude. Finally, Litvin et al. [13] also suggested approaches for the computerized simulation of meshing of aligned and misaligned involute helical gears.

This study investigates both the TCA and transmission error of the work gear pair generated by a modified VTT hob in its profile and longitudinal directions. Firstly, a general mathematical model is established for the modified VTT hob profile, and the hob's variable tooth thicknesses are considered as design parameters. When the parameters of VTT hob are equal to zero, the hob represents a conventional one. The proposed VTT hob can be manufactured by a commercial gear grinder. In this study, the related coordinate systems for simulation of a CNC hobbing mechanism are established, and can also be used for development of the mathematical model of work gear pairs. The gear tooth contact simulations of the work gear pairs, generated by the VTT hob and conventional hob, respectively, are then investigated by applying the TCA method and contact surface topology method [14]. Three numerical examples are presented to illustrate the gear tooth surface topologies, contact ellipses, and transmission errors of the proposed work gear pairs. By comparison of the TCA simulation results, the merits of the gear pairs generated by the proposed generation method with the modified VTT hob can be clearly verified.

2. Mathematical model of the modified hob with variable tooth thickness (VTT)

Basically, the theoretical tooth profile of a hob is a helical gear that can be generated by a rack cutter. In this study, however, the proposed modified VTT hob can be generated by a modified rack cutter. The tooth thickness of the rack cutter is modified along its helix line as shown in Fig. 1, and along its profile line as shown in Fig. 2. The helix angle of the rack cutter is equal to the standard helix angle at the reference point P, which is located at the middle transverse section of the rack cutter. The helix line of the rack cutter is modified by a second order polynomial, as expressed in Eq. (17). A schematic relationship among coordinate systems for generation of the modified VTT hob is shown in Fig. 3. Coordinate systems $S_7(x_7,y_7,z_7)$, $S_p(x_p,y_p,z_p)$, and $S_q(x_q,y_q,z_q)$ are

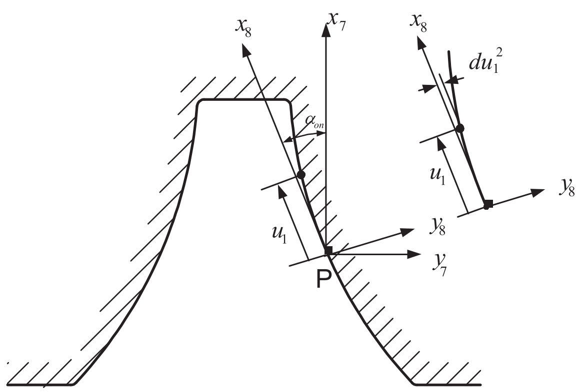

Fig. 2. Profile and its parameters of the modified VTT rack cutter.