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Comparative analysis of meshing characteristics with respect to different meshing rollers of the toroidal drive

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Abstract

This paper investigates meshing characteristics of the toroidal drive with different roller shapes, examines the effect on the characteristics from roller shapes and produces a comprehensive comparative study. Based on the coordinate transformation, the paper introduces the generic models of meshing characteristics and characterizes the meshing to introduce both undercutting and meshing limit curves. The paper further develops meshing functions and their derivatives with respect to each drive type with a different roller shape. This leads to a comprehensive examination of each meshing characteristics against each drive type of a roller shape. The comparative study focuses on the effect of contact curves, tooth profile, undercutting, meshing limit curves and the induced normal curvature. This helps develop the tooth profile of the sun-worm, characterize undercutting and meshing limit curves with different roller shapes and identify the roller shape with the least induced normal curvature. The study is then extended to contact stress comparison and to verifying the least contact stress of the roller type. This naturally leads to an examination of manufacturability with respect to different roller types.

Keywords: Toroidal drive; Roller shape; Meshing; Mathematical modeling; Epicyclic gear train; Manufacturing

1. Introduction

The toroidal drive [1–4] offers the advantages such as a high horsepower-to-weight ratio, coaxial configurations, compactness, and high operating efficiencies. It combines most of the positive attributes of a circular worm-gear drive and an epicyclic gear drive without their negative aspects due to the introduction of rollers in meshing contact with rolling movement between a sun-worm and planet worm-gears, and between a stationary internal gear and planet worm-gears.

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Using rollers as meshing media is popular in mechanical transmissions such as ball screws, roller gear cams, roller enveloping worm drives, cycloid drives, and the toroidal drives. Meshing via rollers which leads to rolling contact has the advantages of lower noise and higher transmission efficiency. It has a substantial effect on meshing characteristics. Though the effect of meshing rollers has not been studied in toroidal drives, the study of meshing rollers in other types of mechanical transmission has been progressing. Gong and Zhu [5] proposed a rolling conical enveloping circular worm drive which was composed of a turret with conical rollers and a circular worm. They developed the meshing equation and completed the manufacturing and test of this type of reducers. Yan and Chen [6] developed equations for the surface geometry of roller gear cams with cylindrical rollers and presented the mathematical expressions for the principal curvatures and directions and the pressure angles. Tsay et al. [7] presented a method of generating a cam surface based on rigid body transformations between a cam and turret rollers and completed the analysis of the pressure angle. Tsay and Ho [8] investigated effects on the output of a cam mechanism owing to clearances in a grooved cam and in roller bearing, the preload between the cam and its turret wheel and the cam taper angle based on the kinematics and geometric relationships between the cam and its roller-follower turret. Cierniak and Eschweiler [9] examined a kind of worm drives composed of a turret with cylindrical rollers and completed the manufacturing of the reducer of proposed drive. Cai and Yao [10] developed the worm-tooth analysis and manufacturing for the rolling spherical enveloping circular worm-gear drive system. Wang et al. [11] studied a modified hyperboloidal roller follower for a spatial roller gear cam mechanism which can be utilized to avoid the edge contact phenomenon between a roller and its mating cam surface. Further, Lai [12–14] used a conjugate surface to investigate the geometric design of roller drives which have cylindrical meshing elements.

It can be seen that meshing rollers have an significant effect on the meshing characteristics of other gear trains. Based on the geometrical analysis and mathematical modeling [15], this paper investigates the effect of these rollers on the meshing characteristics of the toroidal drive, characterizes the toroidal drive properties with different shapes of rollers and develops the mathematical models of the contact curve, the meshing surface, undercutting and meshing limit curves and the induced normal curvature based on different rollers. The paper provides a comparative study of meshing properties with different rollers including their effects on contact stress and tooth profile machining.

2. The coordinate systems and transformation

The toroidal drive in Fig. 1 is a specific type of an epicyclic gear train with a stationary internal toroidal gear and is driven by a sun-worm with angular speed ω_1 transmitted through planet worm-gears to the output

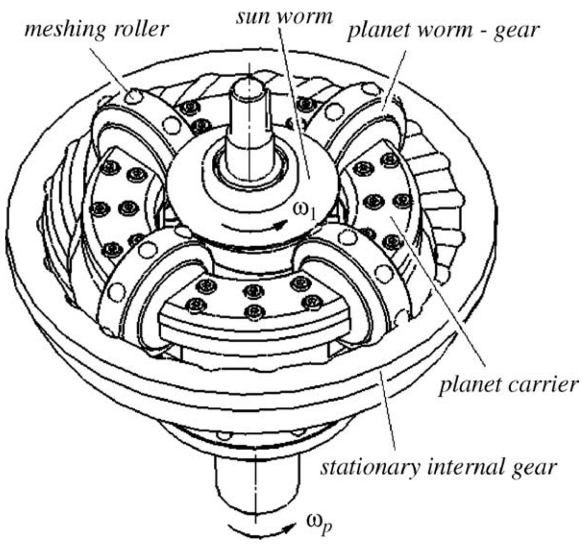

Fig. 1. The toroidal drive.