Mechanism and Machine Theory 49 (2012) 270–283

Contents lists available at SciVerse ScienceDirect

Mechanism and Machine Theory

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

Generation and investigation of a new cycloid drive with double contact

Bingkui Chen *, Hui Zhong, Jingya Liu, Chaoyang Li, Tingting Fang

The State Key Laboratory of Mechanical Transmission, Chongqing University, No. 174 Shazheng Street, 400030 Chongqing, China

ARTICLE INFO

Article history:
Received 5 October 2010
Received in revised form 25 September 2011
Accepted 3 October 2011
Available online 8 November 2011

Keywords:
Cycloid drive
Double-enveloping
Double contact lines
Meshing characteristic
Induced normal curvature

ABSTRACT

A new cycloid drive with double contact lines between one tooth pair is presented in this paper. The new conjugated tooth profile is generated by applying double-enveloping gear theory in cycloid drives. Based on coordinate transformation and gear geometry theory, the meshing equation for this new cycloid drive is established at first, then the equation of tooth profile and meshing line and the formula of induced normal curvature are also derived. The meshing characteristics are investigated by theoretical analysis and numerical examples: the double contact characteristic is revealed by that the meshing function can be resolved into two independent factors; the contact lines at different instant and meshing line are illustrated based on a numerical example; the superior characteristics of the new conjugated tooth profile is represented by comparison of induced normal curvature with conventional cycloid drives. The physical prototype is trial-produced and the transmission error of the prototype is also tested, which shows that double-enveloping theory can be applied for cycloid drives.

1. Introduction

Cycloid drives have been popular gear reducers in many industrial areas for speed, torque conversion, due to their large transmission ratio, compact size, large load capacity, and high efficiency. In recent years they are used more and more widely in precision transmission, such as robot and aerospace area, because of their superior characteristic: theoretically half of the teeth mesh simultaneously; the outstanding averaging effect of errors leads to high precision; compared to strain wave gear reducer, there is no flexible element in cycloid drive which can lead to high stiffness.

The researchers have been done a lot of research about cycloid drives, including conjugated tooth surface, meshing characteristic, dynamic analysis, and so on. Litvin et al. derived the equations of meshing and the conjugated tooth profile for cycloid drive, and also did research on tooth contact characteristic, such as surface singularities and contact line [1, 2]. Li and Hong established the general equation of cycloid gear, which is considered as the combination of shift modification, equidistance modification, and rotating angle modification [3]. Lai established the mathematical model and meshing equation based on coordinate transformation, enveloping theory and conjugated surfaces theory, he also studied the design procedures and machining method of the epicycloid gear [4]. Chen et al. established the universal equation of cycloid gear tooth profile based on cylindrical pin tooth and given motion, they also analyzed the meshing characteristics in detail according to gear geometry [5]. Gorla et al. proposed a new cycloid gear reducer, which has an external ring gear and engaged with the planet wheel by means of cylindrical rollers, and also made a theoretical and experimental investigation on this cycloid speed reducer [6]. Neagoe et al. proposed a new variant of a cycloid planetary transmission with modified structure, which is able to accomplish high kinematical ratio and high efficiency, and useful to fit mechatronic systems of Renewable Energy System [7]. Jorgensen et al. proposed a new permanent-magnet gear based on the cycloid gearing principle, and this new gearing is characterized by an extreme torque density and a very high gearing ratio [8]. Hwang and Hsieh created a mathematical model of the cycloid gear reducer with tooth difference, derived a simpler dimensionless equation of undercutting, and developed a more explicit procedure to determine the feasible design region without undercutting on the tooth profile or interference between the

* Corresponding author. Tel.: +86 23 65106247; fax: +86 23 65106247.
E-mail address: bkchen@cqu.edu.cn (B. Chen).

0094-114X/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechmachtheory.2011.10.001

pins [9, 10]. Shan et al. set up an analytic mathematic model of a double-crank ring-plate-typed pin-cycloid gear planetary drive, and analyzed its nonlinear characteristics [11]. Yang et al. tested a double crank four ring-plate-type cycloid reducer to identify the noise source of the reducer, and proposed noise reduction measures for each of these noise sources [12]. Xu et al. analyzed power flow of the cycloid gear train using multi-body dynamic simulation technique, and put forward a combined wheel tooth modification approach to reduce the transmission error in precision transmission system [13]. Cochran and Bobak proposed a method for utilizing vibration analysis in order to identify a defective cycloid ring gear housing, disk, and eccentric bearing [14]. Kim et al. studied the torsional rigidity of a two-stage cycloid drive using finite element analysis [15].

The cycloid drives studied in the above research have a common characteristic: single contact line between one meshing tooth pair. In certain conditions, the tooth pair flanks can have two distinct contact lines at the same time: this phenomenon is known as secondary action. Applying this phenomenon, new conjugated tooth profile with double contact lines can be generated using double-enveloping method. Sakai and Maki firstly investigated the basic character of the secondary action of the skew gears, especially the worm gears [16], and then many researchers did various research about this phenomenon on double-enveloping worm gears [17, 18]. However, these researches on double-enveloping gear transmission mainly limited to skew axis, especially on worm gears. The cycloid drive is a parallel axis gear transmission, and the research on double-enveloping theory for cycloid drives is very little or lack of systematic theoretical analysis. Chen and Wu studied the secondary action phenomena of the gear drives [19, 20], they also made some research about this phenomenon on cycloid pump. Vecchiato, Demenego and Litvin et al. developed and investigated the geometry of the cycloid pump, which shows that the double-enveloping method can be used in cycloid drives [21, 22]. Chen et al. verified that there are certain points on pin tooth which contact twice with cycloid gear in cycloid drives by analyzing the pin angle function [5]. Zhu proposed a method for the calculation equation of conjugate curve of the trochoidal gears based on the double-enveloping principle [23]. Qiao et al. proposed a method to obtain the secondary cycloid conjugate curves by getting the conjugate points one by one [24].

In this paper a new cycloid drive is generated by applying double-enveloping gear theory in cycloid drives. The main characteristic of the new cycloid drive is that there are double contact lines in a certain meshing area. The double contact lines and the superior characteristic of the new contact line can improve the load capacity and the transmission precision of the gear reducer. In this paper, based on coordinate transformation and gear geometry theory, the meshing equation for this new cycloid drive is established at first, then the equation of tooth profile and meshing line and the formula of induced normal curvature are also derived. The meshing characteristics are investigated by both theoretical analysis and numerical examples. A physical prototype is trial-produced and the transmission error of the prototype is tested to show that double-enveloping theory can be applied for cycloid drives.

2. Principle of double-enveloping cycloid drives

According to the kinematics method of gear geometry theory, the conjugated meshing tooth profile can be obtained based on the original tooth profile and the given relative motion: the points on the conjugated meshing tooth profile are the results of coordinate transformation of the points on the original tooth profile that satisfy the meshing equation [20, 25]. The meshing equation is as

$$\phi = n_q \cdot v_q^{(ab)} = 0 \tag{1}$$

where n_q represents the unit normal vector to the tooth profile at the meshing point in coordinate system q; $v_q^{(ab)}$ represents the relative velocity of the member a with respect to member b at the meshing point in coordinate system q.

The conjugated meshing gear pair of conventional cycloid drive is composed by planetary cycloid gear and the cylindrical pin rollers. From the viewpoint of kinematics method of gear geometry, the cycloid gear tooth profile can be generated by using cylindrical pin roller as a cutter tool and the given enveloping motion. Further, if the cycloid gear is used as the cutter tool, given the same enveloping motion, a new tooth profile can be generated. This new tooth profile is called double-enveloping tooth profile in this paper, which has very different characteristic with pin rollers. The double-enveloping tooth profile has two portions, and one of them is the part of the pin roller. In this paper, the new cycloid drive whose conjugated tooth pair is composed by cycloid gear and double-enveloping tooth profile is called double-enveloping cycloid drive, whereas the conventional cycloid drive is also called single-enveloping cycloid drive; the motion which generates the cycloid tooth profile using cylindrical pin tooth as the cutting tool is called the first enveloping motion, whereas the motion which generates the double-enveloping tooth profile using cycloid gear as the cutting tool is called the second enveloping motion.

3. Double-enveloping tooth profile

3.1. Coordinate systems

The coordinate systems are established according to the right-hand rule and shown in Fig. 1, where member 1 is the internal wheel and member 2 is the planetary cycloid gear. The moving coordinate systems $O_bX_1Y_1Z_1$ and $O_gX_2Y_2Z_2$ are rigidly connected to the centers of internal wheel and the planetary cycloid gear, respectively. The fixed coordinate system OXY is connected to the center of internal wheel. In the initial position, the axes X_1 and X are coincident, X_2 is parallel with X. The axes Z, Z_1 and Z_2 are parallel with each other. The radius of pin teeth distributed circle is R_z, and the radius of pin tooth is r_z. The tooth numbers of internal wheel and planetary cycloid gear are z_b and z_g, and the gear center distance is e. The method in case of crank arm O_bO_g being fixed is adopted to simplify the discussion, and i represents the transmission ratio of the transform mechanism.